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DEVELOPMENT OF DESIGN, TEST AND
ACCEPTANCE CRITERIA FOR ARMY HELICOPTER
TRANSPARENT ENCLOSURES

Leonard M. Cook, et al

PPG Industries, Incorporated

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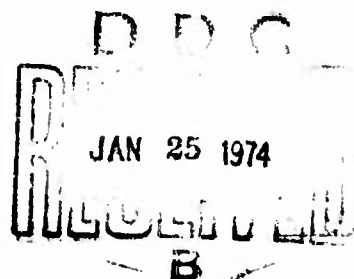
DEVELOPMENT OF DESIGN, TEST, AND ACCEPTANCE CRITERIA FOR ARMY HELICOPTER TRANSPARENT ENCLOSURES

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By

Leonard M. Cook
Glenn E. Freeman
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September 1973



EUSTIS DIRECTORATE

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13. ABSTRACT <p>Because of the U.S. Army's growing concern for the high frequency of transparency replacement, a program to improve the overall reliability and maintainability of helicopter transparencies by appropriate development of design, test, and acceptance criteria was conducted.</p> <p>A survey of representative users indicated that the most serious problem in the replacement of windshields, which are the most critical transparencies, was scratches caused by wiper operation on plastic surfaces. Another serious problem, experienced by laminated windshields, was related to the all-weather capability, with reasons for replacement being delamination and heating failures. These failures occurred on all laminated windshield designs. The primary reason for replacement of nonwindshield transparencies was breakage, since reduced quality is more tolerable with these than it is with windshields.</p> <p>Analysis of all available specifications for windshields indicated that wiper abrasion resistance is seldom specified whereas heating requirements are always addressed. Military specifications for windshields and some other parts are lacking, and actual qualification tests for finished products are incomplete. The developed specification attempts to correct this inadequacy by proposing a complete document that is applicable for all transparencies on current and near-future rotary-wing aircraft. Bird impact tests of current and some potential windshield designs indicate that present glass-laminates and 1/4-inch stretched acrylic do not have a strike resistance beyond 100 mph, whereas the use of polycarbonate achieves a resistance at a speed of at least 200 mph.</p>		

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Transparent Enclosures Helicopter Windshields Glass Plastics Laminates Abrasion Resistance Defogging/Anti-icing/Deicing Birdproofing Coatings Ballistic Tolerance						

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DEPARTMENT OF THE ARMY
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This report was prepared by PPG Industries under the terms of Contract DAAJ02-72-C-0073. It presents the results of an effort to develop improved design, test, and acceptance criteria for helicopter transparent structures to meet the mission requirements of present and future Army helicopters.

This investigation resulted in a proposed set of design, test, and acceptance criteria applicable to transparent inclosures for all rotary-wing aircraft. Some of the criteria relate to all-weather capability, optical and structural quality, abrasion resistance, safety, and bird and ballistic resistance.

In general, an attempt was made analytically to establish optimum criteria to meet all the objectives except for visual reflections, static discharge, and heat transfer. Since most of the technology now available would dictate the use of coatings to meet the criteria, the result would be reduced light transmission and abrasion resistance, especially for plastic substrates. Obviously, some adjustments are needed to address the requirements of visual and radar reflectivity, static discharge, and heat transfer.

It is stressed that these design, test, and acceptance criteria were developed as a result of field investigations and analysis of currently available data and are not the result of any empirical effort. Caution must be exercised in accepting any of the values, classifications, or proposed testing procedures. These criteria should be judged solely on the basis of the data presented in this report; no other assumptions should be made. Further effort is planned to verify these criteria empirically.

A parallel investigation has been conducted by the Goodyear Aerospace Corporation and will be reported separately.

This report has been reviewed by the Directorate and is considered to be technically sound.

The technical monitors for this contract were Major Andrew E. Gilewicz and Mr. Thomas E. Condon of the Military Operations Technology Division of this Directorate.

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Final Report

by

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Prepared by

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Creighton, Pennsylvania
Huntsville, Alabama

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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ABSTRACT

Because of the U. S. Army's growing concern for the high frequency of transparency replacement, a program to improve the overall reliability and maintainability of helicopter transparencies by appropriate development of design, test, and acceptance criteria was conducted.

A survey of representative users indicated that the most serious problem in the replacement of windshields, which are the most critical transparencies, was scratches caused by wiper operation on plastic surfaces. Another serious problem, experienced by laminated windshields, was related to the all-weather capability, with reasons for replacement being delamination and heating failures. These failures occurred on all laminated windshield designs. The primary reason for replacement of nonwindshield transparencies was breakage, since reduced quality is more tolerable with these than it is with windshields.

Analysis of all available specifications for windshields indicated that wiper abrasion resistance is seldom specified whereas heating requirements are always addressed. Military specifications for windshields and some other parts are lacking, and actual qualification tests for finished products are incomplete. The developed specification attempts to correct this inadequacy by proposing a complete document that is applicable for all transparencies on current and near-future rotary-wing aircraft. Bird impact tests of current and some potential windshield designs indicate that present glass-laminates and 1/4-inch stretched acrylic do not have a strike resistance beyond 100 mph, whereas the use of polycarbonate achieves a resistance at a speed of at least 200 mph.

FOREWORD

The work reported herein was authorized by contract no. DAA J02-72-C-0073 issued by the Eustis Directorate, United States Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The work was performed by PPG Industries, Creighton, Pennsylvania and Huntsville, Alabama.

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INTRODUCTION

As a result of recent conflicts, the rotary-wing aircraft has achieved a definite status in Army Aviation. Since numbers of such aircraft have steadily increased, their utilization has also grown at a rapid rate. Consequently, problems of relatively insignificant monetary value for a single occurrence become very important if they prevail across the fleet. Since transparent structures are an example of such a case with apparent high frequency of replacement, this study was instituted by the Eustis Directorate of the United States Army Air Mobility Research and Development Laboratory. The primary objective of this study was to improve the overall reliability and maintainability of helicopter transparencies by appropriate development of design, test, and acceptance criteria. The approach consisted of: 1. conduct a survey to determine the problem areas and the inadequacy of appropriate documents such as specifications and manuals; 2. develop a complete and comprehensive specification that is applicable to all transparencies of current and near-future rotary-wing aircraft.

In the preliminary part of this study, both objective and subjective data was collected from helicopter manufacturers and military organizations. The objective data consisted of design drawings, specifications, aircraft profiles, tests and results, failure mode and rate information on the basis of replacements, spares or repairs, and preventive maintenance procedures. Subjective data relative to installation problems, service complaints, failure modes, and operational environment were collected by personal interviews of experienced pilots and reliability, maintenance, and engineering personnel. To achieve continuity and expand the scope of this subjective data acquisition a questionnaire was utilized.

All available specifications obtained from the helicopter manufacturers and military organizations were reviewed and analyzed. These applicable military, industrial, and federal documents defining the requirements and specifications of helicopter transparencies are presented in condensed form in Appendix I.

Comments and effects of the operational environment on helicopter transparencies are presented and discussed in Appendix II. Indications of the performance of transparencies based on failure modes, replacement rates, and interviews are tabulated in Appendix III. Analysis of military and commercial documents addressing transparency maintenance is presented in Appendix IV. Comments from the questionnaires are included to demonstrate actual service conditions.

Results of 4-lb bird impact tests of current and other potential transparency constructions are presented in Appendix V.

ROTARY-WING AIRCRAFT

Based on discussions with Army personnel, the following current aircraft constitute the backbone of the near-future fleet:

CH-47	Chinook
CH-54	Tarhe (Crane)
UH-1	Iroquois (Huey)
AH-1G	Cobra
OH-58	Kiowa
OH-6	Cayuse
TH-55	Osage

All seven of the helicopters fall within the five main rotary-wing classifications of cargo, utility, attack, observation, or trainer.

Trainer

Recent trends have de-emphasized the use of a rotary-wing aircraft as a primary trainer, since actual training is quite often dependent on the type of helicopters and the degree of subsystems sophistication. Also, information on the TH-55 obtained in the preliminary study was rather sparse. Therefore, this group shall not receive any consideration in the proposed specification. Any needs that do occur should be met by utilizing the observation category.

Observation

Helicopters or rotary-wing aircraft within this class are utilized in missions of visual observation, target acquisition, armed reconnaissance, and command and control. They also have some degree of load capacity and training as necessary.

Attack

Rotary-wing aircraft within this classification is considered a complete weapons system with the primary function of combat missions.

Utility

As the above term implies, the mission requirements of helicopters in this class tend to overlap into attack and cargo. Utility aircraft can function as cargo, transport of heavy equipment, personnel transport, and tactical utility missions.

Cargo

Aircraft within this class function as troop transport, heavy cargo, and combat missions. The CH-47 is the only current aircraft within the Army fleet with all-weather capability. The CH-54 with heavy cargo capacity does not have the all-weather capability.

TRANSPARENCIES

For the purpose of this study, transparent structures in rotary-wing aircraft shall be grouped into windshield-type transparencies directly in front

of the pilot, and lower, upper, and side cockpit enclosures and cabin windows. All such transparencies have the general requirement of interior environment, which is defined as letting the light in to create a livable condition. Along with this, all transparent structures must permit some degree of vision without extreme distortion that could distract an individual's mission or create physical or mental anguish.

Normally, transparent structures in rotary-wing aircraft, at least up to the present, are not load-bearing members of the aircraft structure. Hence, any loading that transparencies experience is caused by operation, environment, man, or installation. Since engineers and designers have a realistic understanding of such loads, they are usually appropriately considered, but man remains the most unpredictable factor.

Beyond the above-listed general functions, the transparency directly in front of each pilot (main windshield) has the special functional requirement as detailed by FAR-27 and 29 (Appendix I): "Each pilot shall have a safe and undistorted view along the flight path during day and night operation without glare or reflections. Sufficient view must be maintained during exposure to the elements and the actual material must be of the safety type". This federal standard lists a certification as applicable for anti-ice and defog systems. The federal standards for fixed-wing aircrafts FAR-23 and 25 (Appendix I) have additional requirements for structural quality, fail safety and bird proofing, as applicable. Inclusion of all such requirements certainly enhances the inherent capability of the most important transparent member and requires complete and detailed specifications. The secondary windshield is usually considered as a transparency within the realm and repeated use of each pilot, but not directly in front of each pilot.

TRANSPARENCY EXISTENCE PER AIRCRAFT MISSION

Table 1 shows the general existence of transparency of a particular type per given mission.

TABLE 1. TRANSPARENCY EXISTENCE				
Transparency	Aircraft Mission			
	Cargo	Utility	Attack	Observation
Main Windshield	Yes	Yes	Yes	Yes
Secondary Windshield	Yes	No	Yes	No
Lower Window	Yes	Yes	No	Yes
Side Window	Yes	Yes	No	Yes
Upper Window	Yes	Yes	No	Yes
Cabin Window	Yes	Yes	No	Yes

In general, the mission requirements of cargo and utility aircraft are quite similar, and the transparencies show much agreement except for a secondary

windshield. However, it appears very likely that a utility-type aircraft could be expanded to include a secondary windshield in the future. For the purpose of this study, we will combine cargo and utility into one group.

The auxiliary transparencies in the attack aircraft do not directly fit into any classification within the cockpit enclosure. Since the major portion of the transparency acts like a canopy, we shall consider these panels to be secondary windshields.

Thus, for the purpose of this study, Table 2 defines the rotary-wing aircraft transparencies.

TABLE 2. TRANSPARENCY CLASSIFICATION	
Type	Functional Description
I	Main windshield directly in front of each pilot
II	Secondary or intermediate windshield not directly in front of pilot
III	Lower cockpit enclosure (nose bubble)
IV	Side cockpit enclosure (side, door windows)
V	Upper cockpit enclosure (eyebrow, roof windows)
VI	Cabin transparent enclosure (cabin, cargo door windows)

DESIGN OBJECTIVES

The parameters considered in this study are the following:

1. Anti-ice/Defog Methods
2. Rain Removal Methods
3. Optical Quality
4. Fracture Resistance
5. Abrasion Resistance
6. Reliability
7. Thermal Shock Resistance
8. Fail-Safe Construction
9. Crashworthiness
10. Ballistic Resistance
11. Bird Strike Resistance
12. Vibration Resistance
13. Weight
14. Interchangeability
15. Installation and Removal Techniques
16. Ease of Maintenance
17. Visual Reflection
18. Environmental

19. Chemical Resistance
20. Lightning Strike Resistance
21. Fire Resistance
22. Static Discharge
23. Reduced Radar Reflectivity
24. Heat Transfer
25. Life Cycle Cost

Items 12, 14, 18 and 20 are additional considerations added to the basic list as detailed in the contract.

PROBLEM AREAS

The results of the preliminary study (Appendixes I through IV) indicated the following problem areas.

1. Anti-Ice/Defog - Although some actual heating failures were reported, the majority of the problems related to this system were associated with delamination.
2. Rain Removal - Some vague reports as to the functioning of hot air systems and repeated complaints of restricted wiper use because wipers in conjunction with any grit easily scratched the plastic surfaces.
3. Optical Quality - Considered to be acceptable as received, but rework of scratches produced inferior optics.
4. Fracture Resistance - Some degree of breakage or cracking was reported for all transparencies.
5. Abrasion Resistance - Acrylic or polyester plastic windshields consistently showed abrasion from wipers and/or faulty maintenance. The failure of the plastic panels to resist scratching was the primary difficulty reported.
6. Reliability - This consideration as related to the useful service life was a continuing problem, since some transparencies, especially windshields, experienced rather low operating life ratings.
8. Fail Safe Construction - Cases of implosions or actual falling out of transparencies were reported.
10. Ballistic Resistance - The failure of all parts exposed to combat was apparent, with many replacements necessary because of ballistic damage.
11. Bird Strike Resistance - Some isolated cases of bird strike

failures were reported. No cases of loss of the aircraft caused by bird strike are known.

14. Interchangeability - Not addressed on the majority of the aircraft, causing installation procedures to be more difficult than necessary.
15. Installation and Removal Techniques - In addition to installation problems as related to the transparency design, the glazing materials utilized leaked during operation and at times were very difficult to remove.
16. Maintenance - Corrective techniques such as repairs were well utilized, but actual preventive measures were not adequately documented by applicable procedures.
17. Visual Reflection - Repeated complaints by pilots of glare experienced in night flight were reported. The actual signaling effect has always prevailed as a problem.
18. Environmental - Repeated cases of crazing were apparent.
24. Heat Transfer - The "greenhouse" effect repeatedly cited cases where doors were removed to cool down the enclosures.

With these problem areas under consideration, the parameters described earlier were rated as being of primary, secondary, or third order importance as shown by Table 3. This priority list was used as a guide in developing the specification. The requirements for each design objective were detailed and subsequently optimized relative to the effect on the other objectives. Intended applicability of the requirements as to particular transparencies and their associated tests were prepared. To enhance the consideration of bird strike resistance, fundamental tests were conducted to ascertain velocity limitations of current and future rotary-wing aircraft designs. The results of these tests are presented in Appendix V.

TABLE 3. RELATIVE IMPORTANCE OF DESIGN REQUIREMENTS PER HELICOPTER CLASS			
Design Requirement	Class I Cargo-Utility	Class II Attack	Class III Observation
Anti-Ice/Defog	1	1	1
Rain Removal	1	1	1
Optical Quality	1	1	1
Structural Integrity	1	1	1
Abrasion Resistance	1	1	1
Reliability	1	1	1
Thermal Shock Resistance	1	1	1
Fail-Safe Construction	1	1	1
Crashworthiness	1	1	1
Ballistic Resistance	1	1	1
Bird Strike Resistance	2	2	2
Vibration Resistance	2	2	2
Weight	2	2	2
Interchangeability	2	2	2
Installation/Removal	2	2	2
Maintenance	2	2	2
Visual Reflections	2	2	2
Environmental	1	1	1
Chemical Resistance	2	2	2
Lightning Strike	3	3	3
Fire Resistance	3	3	3
Static Discharge	3	3	3
Radar Reflectivity	2	1	1
Heat Transfer	3	3	3

SPECIFICATION FOR TRANSPARENCIES ON ROTARY-WING AIRCRAFT

The following lists the five general sections and their associated requirements for any transparencies on rotary-wing aircraft.

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This specification establishes the performance requirements, design, and qualification and acceptance test criteria for transparent enclosures used on rotary-wing aircraft. It shall be utilized, as applicable, for formed or flat, laminated or monolithic transparencies such as windshields, lower (nose bubbles), upper (roof, eyebrow), side, and other cockpit windows and cabin windows. To use this specification, the aircraft shall be designated as to a particular class on the basis of aircraft mission and the transparency designated as to a particular type on the basis of transparency function.

Rotary-Wing Aircraft Missions

Class I	Cargo-Utility
Class II	Attack
Class III	Observation

Transparency Functions

Type I	Main windshield directly in front of each pilot
Type II	Secondary or intermediate windshield not directly in front of pilot
Type III	Lower cockpit enclosure (nose bubble)
Type IV	Side cockpit enclosure (side door windows)
Type V	Upper cockpit enclosure (eyebrow, roof windows)
Type VI	Cabin transparent enclosure (cabin, cargo door windows)

2.1 SPECIFICATIONS

MIL-I-8500C	Interchangeability and Replaceability of Component Parts for Aerospace Vehicles
MIL-P-833310	Polycarbonate
MIL-P-25690A	Plastic, Sheets and Parts, Modified Acrylic Base Monolithic, Crack Propagation Resistant
MIL-G-25667A	Glass, Monolithic, Aircraft Glazing
MIL-P-8184B	Plastic Sheet, Acrylic, Modified
MIL-C-25769E	Cleaning Compound, Aircraft Surface, Alkaline Waterbase
MIL-T-5842A	Transparent Areas, Anti-Icing, Defrosting and Defogging Systems

2.2 STANDARDS

MIL-STD-810B	Environmental Test Methods
MIL-E-5272C	Environmental Testing, Aeronautical and Associated Equipment
Federal Test Method Standard 151A	Metal Test Methods
Federal Test Method Standard 406	Plastics: Methods of Testing
Federal Test Method Standard 6053	
LP 406	

The windshield system, which includes the main windshield (Type I) directly in front of each pilot and any secondary or intermediate windshield (Type II), forms part of the cockpit enclosure that must suitably house and protect the crew from the elements. The primary function of the windshield is to provide clear, unobstructed visibility for the forward field of view. Because of the all-weather mission requirements, Class I and II windshields must have a clear field of view at all times.

3.1 ANTI-ICE/DEFOG

- 3.1.1 Each transparency shall have the capability to maintain clear, unobstructed vision for all normal flight profiles under adverse environmental conditions. This requirement is applicable to all transparent areas essential to the mission of the aircraft in accordance with the following applicability list.

Applicable per 3.1

Class I	Type I, II
Class II	Type I
Class III	Type I

Nonapplicable

Type III, IV, V, VI
Type II
Type II, III, IV, V, VI

- 3.1.2 The anti-ice heating system shall be capable of uniformly dissipating at least 3.5 watts per square inch or as specified by MIL-T-5842A.
- 3.1.3 Heating shall be accomplished by means of a transparent electrically conductive film or resistive element buried within the transparency or as specified by MIL-T-5842A.
- 3.1.4 Defogging shall be accomplished by maintaining the interior surface of the transparency above the enclosure dew point temperature.
- 3.1.5 Heat required for defogging shall be accomplished by means of electrically conductive film or equivalent or controlled hot air, as specified by MIL-T-5842A.
- 3.1.6 Electrical characteristics.
- 3.1.6.1 Bus bars of minimum width and capable of carrying the required current shall be applied to the area as per applicable drawings and securely bonded to the substrate. Unless otherwise specified, the width of bus bars shall be 5/16 in. and they shall be so

positioned to afford maximum visibility. The coating or resistive element shall make permanent and uniform contact with the bus bars.

- 3.1.6.2 All solder joints shall be secure and constructed in accordance with high-grade workmanship and aircraft practice. The voltage drop when measured from free end power braid to far end of bus bar shall not be greater than 2.0 volts.
- 3.1.6.3 All internal wiring shall be capable of carrying required current load and shall be sufficiently flexible to withstand expansion and contraction between solder joints due to temperature extremes and vibration.
- 3.1.6.4 Insulation resistance between all electrical conductors not intentionally connected shall be 100 megaohms or greater with no evidence of arcing when subjected to 2200 volts rms.
- 3.1.6.5 Power to the heating film shall be controlled by a temperature sensing element (TSE). The TSE shall have temperature/resistance properties as specified on applicable drawings. Two elements, an operating and a spare, shall be positioned .020 to .040 in. from the conductive film depending on the type of element.
- 3.1.6.6 The bus to bus resistance of the heating film shall be as specified on the applicable drawings. The tolerance of the heating film resistance or equivalent shall be $\pm 15\%$. Load balance between phases of three-phase heating elements shall be $\pm 10\%$ of the average of all three phases.
- 3.1.6.7 The conductive coating or resistive element shall be applied in such a manner that uniform heat dissipation is obtained over the entire anti-iced area with a temperature uniformity of $\pm 10^\circ\text{F}$ based on the control temperature. The heating system shall be free of high-gradient hot spots and cold areas.
- 3.1.6.8 The heating film or resistive element and all electrical connections shall be permanently sealed to prevent moisture penetration.

3.2 RAIN REMOVAL

- 3.2.1 Each transparency shall have a rain-removal system that maintains a sufficient cleared portion affording each pilot clear, unobstructed vision along the flight path. Clearing shall be available at design cruise velocity and be designed for all rain intensities up to "heavy rain" or the equivalent of 0.6 in. per hour.¹
Intended applicability:

¹W. J. Humpherys, PHYSICS OF AIR, New York, Dover Publications, Inc., 1964, p. 280.

Applicable per 3.2Nonapplicable

Class I Type I
 Class II Type I
 Class III Type I

Type II, III, IV, V, VI
 Type II
 Type II, III, IV, V, VI

- 3.2.2 No single malfunction in the removal system shall simultaneously result in a loss of this capability on each transparency.
- 3.2.3 This clearing system shall consist of appropriately designed wipers or equivalent.
- 3.2.4 Each transparency with wipers shall have a windshield washer system

3.3 OPTICAL QUALITY

3.3.1 Distortion

- 3.3.1.1 Each transparency comprising the cockpit enclosure shall demonstrate acceptable optics with no abrupt bending or objectionable blurring of the image viewed through the primary vision area of the transparency.
- 3.3.1.2 Each transparency forming the cockpit enclosure shall be divided into optical grades depending on the crew use relative to each pilot's eye position. Transparencies of Types II, III, and IV within the primary field of vision of each pilot shall have as a minimum a grid line slope of 1 in 8. The critical zone of each Type I main windshield shall have as a minimum a grid line slope of 1 in 12. Transparencies of Types III, IV, and V not in the primary vision area of each pilot shall have as a minimum a grid line slope of 1 in 4. The actual distortion quality respectively graded as A, B, and C shall have the following applicability:

<u>GRADE A</u> (1 in 12)		<u>GRADE B</u> (1 in 8)	<u>GRADE C</u> (1 in 4)
Class I	Type I	Type I, II, III, IV	Type III, IV, V, VI
Class II	Type I	Type I, II	None
Class III	Type I	Type I, II, III, IV	Type III, IV, V, VI

- 3.3.1.3 Each transparency shall have an optical free vision area consisting of a 2-in. peripheral border and 1-in.-wide band associated with heating system isolation lines or as specified by applicable drawings.
- 3.3.1.4 Use of the heating system shall produce no degradation of the prescribed optics requirements.

3.3.2 Minor Optical Defects - All Classes, All Types

Minor optical defects within the vision area or daylight opening of each transparency shall not form an objectionable pattern and shall cause no visual distraction to the pilot.

3.3.3 Light Transmission

Each transparency shall have a minimum light transmission of 70% that shall be maintained throughout the useful life of the transparency. Intended applicability:

	<u>Applicable per 3.3.3</u>	<u>Nonapplicable</u>
Class I	Type I, II, III, IV	Type V, VI
Class II	Type I, II	None
Class III	Type I, II, III, IV	Type V, VI

3.3.4 Haze

Each transparency shall have an original maximum haze of 4% that shall be maintained throughout the useful life of the transparency. Intended applicability:

	<u>Applicable per 3.3.4</u>	<u>Nonapplicable</u>
Class I	Type I, II, III, IV, V	Type VI
Class II	Type I, II	None
Class III	Type I, II, III, IV, V	Type VI

3.4 STRUCTURAL INTEGRITY

3.4.1 General - All Classes, All Types

3.4.1.1 Each transparency shall be so designed and consist of sufficient strength to sustain normal operating or limit loads without detrimental effect or permanent deformation.

3.4.1.2 At any load up to limit loads, the experienced deformation shall not interfere with safe operation.

3.4.2 Each transparency shall be capable of supporting ultimate loads without any detrimental effects.

3.4.2.1 Unless otherwise specified, ultimate loads shall be two times the normal operating loads for each transparency.

3.4.2.2 In addition, ultimate loads for each Type V transparency shall be 200 pounds distributed over an area of 1 square foot.

3.4.2.3 Intended applicability:

Applicable Per		
	<u>3.4.2.1</u>	<u>3.4.2.2</u>
Class I	Type I, II, III, IV, V, VI	Type V
Class II	Type I, II	None
Class III	Type I, II, III, IV, V, VI	Type V

3.5 ABRASION RESISTANCE

- 3.5.1 Each transparency surface shall be sufficient abrasion resistant to scratching, pitting, or marring encountered during aircraft operation, maintenance, and handling.
- 3.5.2 The outboard surface of each transparency shall be highly abrasion resistant to scratching, pitting, or marring encountered during wiper operation, maintenance, and handling.
- 3.5.3 Intended applicability:

Applicable Per		
	<u>3.5.1</u>	<u>3.5.2</u>
Class I	Type III, IV, V, VI	Type I, II
Class II	Type II	Type I
Class III	Type II, III, IV, V, VI	Type I

3.6 RELIABILITY - All Classes, All Types

- 3.6.1 Each transparency shall satisfactorily function according to design without failure or malfunction. The following definitions are applicable.
- 3.6.1.1 Shelf life is defined as the time expended between date of shipment by manufacturer and actual installation of spare part or delivery of aircraft. Shelf life shall be two years.
- 3.6.1.2 Useful life is defined as the actual time in years that the transparency has been installed.
- 3.6.1.3 Operating life is defined as the actual time in hours that the aircraft has operated with the transparency installed.
- 3.6.2 Warranty in Terms of Useful and Operating Life

		<u>Useful Life</u> (Years)	<u>Operating Life</u> (Hours)
Class I	Type I, II	3	3,000
	Type III, IV, V	10	10,000
	Type VI	15	15,000

		<u>Useful Life</u> (Years)	<u>Operating Life</u> (Hours)
Class II	Type I	3	3,000
	Type II	5	5,000
Class III	Type I, II	5	5,000
	Type III, IV, V	10	10,000
	Type VI	15	15,000

3.6.3 Structural Adhesion

No loss of adhesion between the associated structural members, other adhered surface layers, or edging shall develop and be of such extent to impair the normal function of the transparency.

3.7 THERMAL SHOCK RESISTANCE

3.7.1 Each transparency shall be capable of withstanding any rapid changes in temperature within the range from -65°F to +160°F without any detrimental effects

3.7.2 Each transparency with an electrical conductive heating system or equivalent shall be capable of satisfactory performance without deterioration when the heating system is energized to raise the temperature of the heating media from -65°F to +110°F.

3.7.3 Intended applicability:

		<u>Applicable Per</u>
		<u>3.7.1</u> <u>3.7.2</u>
Class I	Type III, IV, V, VI	Type I, II
Class II	Type II	Type I
Class III	Type II, III, IV, V, VI	Type I

3.8 FAIL-SAFE CONSTRUCTION

3.8.1 Each transparency shall be capable of withstanding the normal operating loads after a primary structural member has failed. In event of such failure, residual vision must be available to each pilot.

3.8.2 Intended applicability:

		<u>Applicable per 3.8</u>	<u>Nonapplicable</u>
Class I	Type I, II	Type III, IV, V, VI	
Class II	Type I	Type II	
Class III	Type I	Type II, III, IV, V, VI	

3.9 CRASHWORTHINESS - All Classes, All Types

3.9.1 Each transparency shall be so designed and of sufficient strength to satisfactorily withstand any rapid external load that can be experienced when the helicopter performs an emergency hard landing.

3.9.2 Each transparency shall be flexible enough to deflect, when impacted, absorbing energy; and subsequent failure, if such occurs shall not result in any sharp particles that would be injurious to the crew.

3.10 BALLISTIC RESISTANCE

3.10.1 General - All Classes, All Types

Each transparency, as required, shall provide sufficient residual visibility for each pilot to perform an emergency flight and landing after sustaining damage from a .30 caliber impact. No spall, injurious to the crew, shall be ejected from the inboard surface.

3.10.2 Special as Required Transparent Armor (Non-optimized)

3.10.2.1 Each transparency shall provide V₅₀ protection ballistic limit against small-arms projectiles up to a caliber of .30 APM2 or as otherwise specified.

3.10.2.2 The actual projectile impacts shall not cause any spall to be ejected from the inboard surface, and each transparency shall maintain sufficient visibility for each pilot to complete his mission.

3.10.2.3 Intended applicability:

	<u>Applicable Per 3.10.2</u>	<u>Nonapplicable</u>
Class I	Type I, II, III	Type IV, V, VI
Class II	Type I, II	None
Class III	Type I, II, III	Type IV, V, VI

3.11 BIRD STRIKE RESISTANCE

3.11.1 Each transparency shall be so designed and constructed to prevent penetration by an impacting 4-lb bird when the velocity of the aircraft relative to the bird along the flight path equals the maximum sea level cruise velocity.

3.11.2 Secondary projectiles such as rear-face spall shall either be completely contained by the transparency or be of sufficiently low residual kinetic energy to be noninjurious to aircrew personnel. Intended applicability:

Applicable per 3.11Nonapplicable

Class I	Type I, II	Type III, IV, V, VI
Class II	Type I, II	None
Class III	Type I, II	Type III, IV, V, VI

3.12 VIBRATION RESISTANCE - All Classes, All Types

Each transparency shall satisfactorily withstand vibrations encountered in helicopter operation and flight without any cracking, delamination, or any other deterioration.

3.13 WEIGHT

3.13.1 The weight of each transparency shall be a minimum consistent with this specification.

3.13.2 Calculated on the basis of aerial density, conventional transparencies and any special designs shall not exceed the following limits:

		<u>Aerial Density (lbs/sq ft)</u>		
		<u>Conventional</u>	<u>Per 3.11</u>	<u>Per 3.10.2</u>
Class I	Type I, II	2.6	3.6	10.0
	Type III	1.8	-	10.0
	Type IV, V	1.8	-	-
	Type VI	1.2	-	-
Class II	Type I, II	2.6	3.6	10.0
Class III	Type I, II	2.6	3.6	10.0
	Type III,	1.8	-	10.0
	Type IV, V	1.8	-	-
	Type VI	1.2	-	-

3.14 INTERCHANGEABILITY - All Classes, All Types

Each transparency shall have complete interchangeability as to size, contour, drilled holes and not require any further fabrication during installation as per the requirements of MIL-I-8500.

3.15 INSTALLATION AND REMOVAL - All Classes, All Types

3.15.1 Each transparency shall be attached to the aircraft frame by means of durable fasteners through oversized holes predrilled in the edge attachment or edge reinforcement of the transparency.

3.15.2 Actual fastening and subsequent torquing to 15-20 inch-pounds shall not cause any adverse installation stresses that exceed one-fifth of the nominal strength.

3.15.3 Each transparency shall be mounted with a closed cell silicone gasket or equivalent that shall effectively seal the enclosure against water penetration but shall be easily removed in case of part removal.

3.16 MAINTENANCE - All Classes, All Types

3.16.1 Each transparency shall be capable of functioning with a minimum amount of special maintenance techniques.

3.16.2 The best cleaning method for each transparency (in particular, windshields) shall be directed and officially documented with appropriate manual before the part can be put in service.

3.16.3 As applicable, repair techniques that extend the operating life of each transparency shall be outlined with actual documents presenting the procedures, necessary materials, etc.

3.17 VISUAL REFLECTIONS

3.17.1 General - All Classes, All Types

3.17.1.1 Each transparency of combined structural members, as applicable, shall maintain consistency of the index of refraction with $\pm 5\%$ for all interfacing materials.

3.17.2 Special

3.17.2.1 The interior surface of each transparency shall have a total light reflection in the visible range of not more than 1%.

3.17.2.2 A low-reflective film or equivalent shall be applied with maximum efficiency at the specified wave length and angle of incidence.

Applicable Per 3.17.2

Nonapplicable

Class I	Type I	Type I, II, III, IV, V, VI
Class II	Type I	Type II
Class III	Type I	Type I, II, III, IV, V, VI

3.18 ENVIRONMENTAL - All Classes, All Types

3.18.1 Each transparency shall be functional and maintain satisfactory performance when subjected to all possible environmental conditions. No deleterious effects shall be exhibited by each installed transparency subjected to worldwide extremes in climate, weather, natural exposure, and fungus.

3.18.2 Each transparency shall satisfactorily withstand exposures to the following operational conditions:

- a. Ambient temperatures from -65°F to +160°F
- b. Sunshine
- c. Excessively heavy rain
- d. Blowing snow and impinging ice crystals
- e. 100% relative humidity
- f. Flowing sand
- g. Salt spray
- h. Sulfur dioxide atmosphere
- i. Fungus

3.19 CHEMICAL RESISTANCE - All Classes, All Types

Each transparency shall exhibit no evidence of crazing, cracking, or other chemical degradation when exposed to high atmospheric concentrations or actual contact of solvents or solutions normally used in conjunction with aircraft.

- a. Jet fuel, JP-4 and JP-5
- b. Isopropyl alcohol
- c. Ethylene glycol
- d. Lubrication oils
- e. Grease
- f. Hydraulic fluids
- g. Airplane wash MIL-C-25769E
- h. Bug removal fluid P-6009
- i. Windshield cleaner MIL-C-18767A, Type I

3.20 LIGHTNING STRIKE RESISTANCE

Each transparency shall have a metallic type edging or retainer to dissipate a charge from lightning. Intended applicability:

	<u>Applicable Per 3.20</u>	<u>Nonapplicable</u>
Class I	Type I, II	Type III, IV, V, VI
Class II	Type I, II	None
Class III	Type I, II	Type III, IV, V, VI

3.21 FIRE RESISTANCE - All Classes, All Types

Each transparency shall consist of materials that are self-extinguishing, nonflammable, or burn at a maximum rate that does not exceed 2.5 inches per minute.

3.22 STATIC DISCHARGE

The surface resistivity of the outboard structural member of

each transparency shall not exceed 10^8 ohms per square. Intended applicability:

	<u>Applicable Per 3.22</u>	<u>Nonapplicable</u>
Class I	Type I, II	Type II, III, IV, V, VI
Class II	Type I	Type II
Class III	Type I	Type II, III, IV, V, VI

3.23 RADAR REFLECTIVITY

Each transparency shall have a low resistance, transparent, metallic or metal oxide, radar reflective film of 15 ohms per square, maximum, buried within the transparency. Intended applicability:

	<u>Applicable Per 3.23</u>	<u>Nonapplicable</u>
Class I	Type I, II	Type III, IV, V, VI
Class II	Type I, II	None
Class III	Type I, II	Type III, IV, V, VI

3.24 HEAT TRANSFER

Each Type V transparency of the cockpit enclosure or as otherwise required shall retard heating of the cockpit enclosure by reducing the actual amount of transmitted solar energy. Intended applicability:

	<u>Applicable Per 3.24</u>	<u>Nonapplicable</u>
Class I	Type I, II, V	Type III, IV, VI
Class II	Type I, II	None
Class III	Type I, V	Type II, III, IV, VI

4.0

QUALIFICATION TESTS

Qualification tests will be conducted on full-size panels or approved representative samples of equivalent design to substantiate the satisfactory performance of the transparency and demonstrate the conformance relative to the requirements of this specification. Once a transparency or a transparency set of duplicate panels symmetrical with respect to the aircraft centerline has successfully achieved the level of performance as detailed by the Qualification tests, the requirements of section 4.0 are considered to be accomplished for all production parts of similar design. The following qualification tests shall be conducted for each transparency as required per the applicability of the specific requirements as detailed in section 3.0. All full-size qualification panels, must conform to the design requirements of this specification but representative samples need not conform to the optics requirements. To be considered acceptable, qualification tests conducted, as required, shall cause no detrimental effects, and after completion of the qualification tests, the transparency must continue to conform to the Acceptance Test of 5.0.

In some cases, qualification per requirement may be successfully accomplished by analytical means as applicable or by similarity. However, actual address to this particular approach must occur in the specific test requirement to be valid.

4.1

ANTI-ICE/DEFOG ANALYSIS

The anti-icing requirement as specified by 3.1.1 shall be substantiated by analysis and laboratory tests. A complete thermal analysis per conditions of MIL-T-5842A shall be completed to show that the required amount of heat is conducted to the outer surface and that the outer surface temperature is maintained at a minimum of 35°F. This analysis shall consider heat flow into the cockpit so adequate de-fogging is also maintained.

4.2

ANTI-ICE/CYCLIC TEST

4.2.1

Criteria

Cyclic laboratory tests shall be conducted on each full size transparency, to substantiate satisfactory performance of the transparency's heating system without any deterioration when exposed to repeated heating at 0°F.

- 4.2.2 The transparency shall be operated with design operating voltage while exposed to the following environmental conditions. The transparency shall be placed in an environmental chamber maintained at -25°F . Operating voltage shall be applied through a suitable electrical controller with the windshield temperature sensing element connected to the controller. The windshield shall be allowed to cycle at design operating temperature for a period of 10 minutes. Power shall then be turned off and the windshield allowed to cool down. When the transparency temperature reaches 0°F , power shall again be applied. One cycle shall be as defined per Figure 1, and 1000 complete cycles shall be completed.

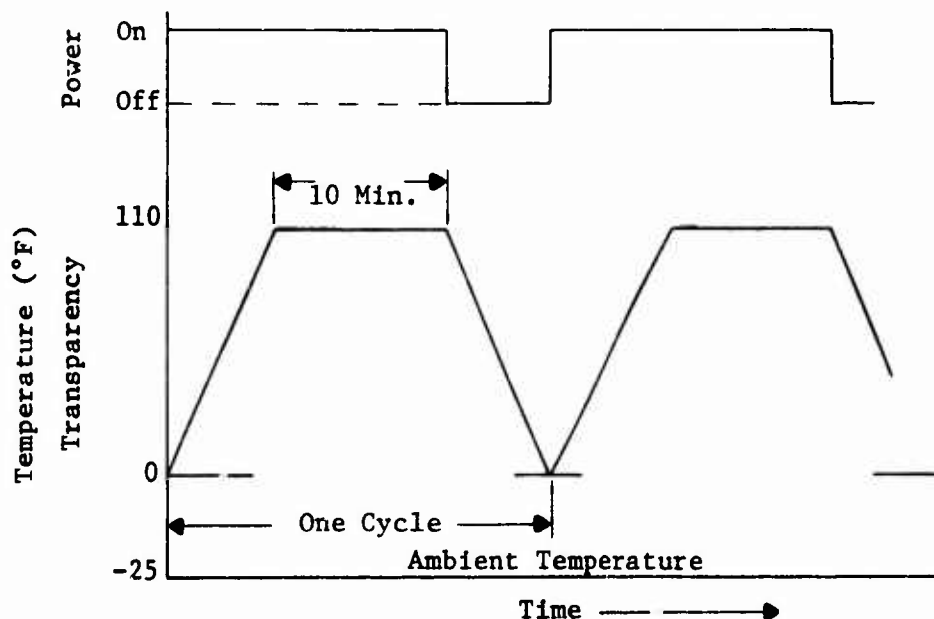


Figure 1. Cyclic Test.

4.3 THERMAL SHOCK

4.3.1 Criteria

- 4.3.1.1 Each transparency shall satisfactorily withstand the thermal shock cycle test as defined per MIL-STD-810B, Method 503. A total of ten cycles shall be conducted for qualification. Where applicable, transparencies constructed of materials of well-known properties and application shall be qualified by similarity and analysis.

- 4.3.1.2 In place of the test requirements as defined by 4.3.1.1, electrically heated transparencies as required by 3.1.1 shall be thermally shock tested utilizing the heating system.

4.3.2 Test

The transparency mounted in a suitable frame to simulate installation shall be placed in a test chamber maintained at $160^{\circ}\text{F} \pm 5^{\circ}\text{F}$. The transparency shall be exposed to this temperature for a period of at least 4 hours. The part shall then be removed from the heated chamber and within a maximum of 5 minutes be transferred to a cold chamber maintained at $-65^{\circ}\text{F} \pm 5^{\circ}\text{F}$. The transparency shall be exposed to this temperature for a minimum of 4 hours. This constitutes one complete cycle. A total number of 10 cycles shall be completed for each transparency without any interruption in the test sequence.

4.3.3 Electrically Heated Transparency Test

The transparency mounted in a suitable frame to simulate installation shall be placed in a cold chamber having an environmental air temperature of $-65^{\circ}\text{F} \pm 5^{\circ}\text{F}$ and allowed to soak for 2 hours. The transparency shall then be energized with nominal operating voltage until design operating temperature is indicated by the temperature sensing element. The voltage is then shut off and the transparency allowed to cool to ambient temperature. A cycle shall be as defined by Figure 2, and a total of 50 such cycles shall be completed.

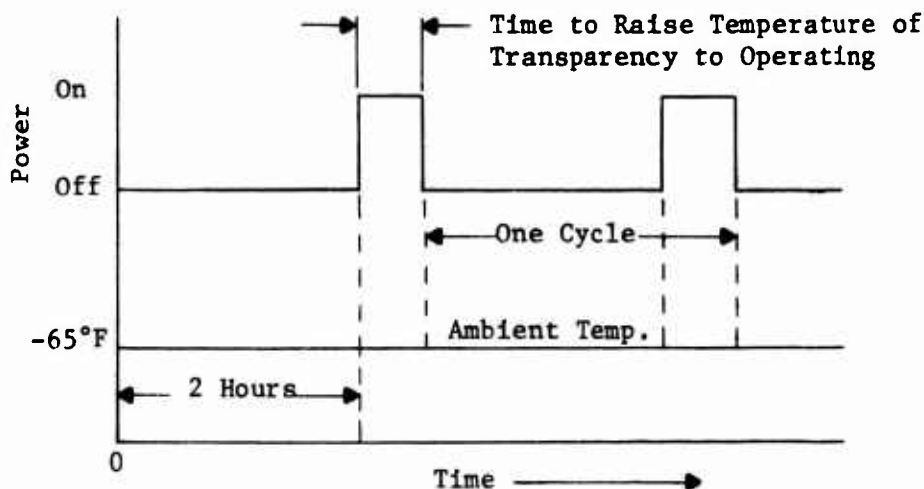


Figure 2. Thermal Shock Test for Electrically Heated Transparencies.

4.4 LIFE CYCLE TEST

4.4.1 Criteria

- 4.4.1.1 Each transparency as defined by 3.1.1 shall be subjected to the combined loading effects of pressure differential, thermal gradients, and vibration.
- 4.4.1.2 Sufficient instrumentation shall be incorporated to determine maximum stress levels.
- 4.4.1.3 Each transparency submitted for this test shall have previously completed all required environmental tests as defined by 4.10.

4.4.2 Test

The transparency shall be mounted to a test fixture that simulates installation. Vibration shall be as defined in Procedure I, Curve B, Method 514 of MIL-STD-810B or as otherwise specified. Test cycle shall be as per Figure 3, and a minimum of 50 complete cycles shall be accomplished.

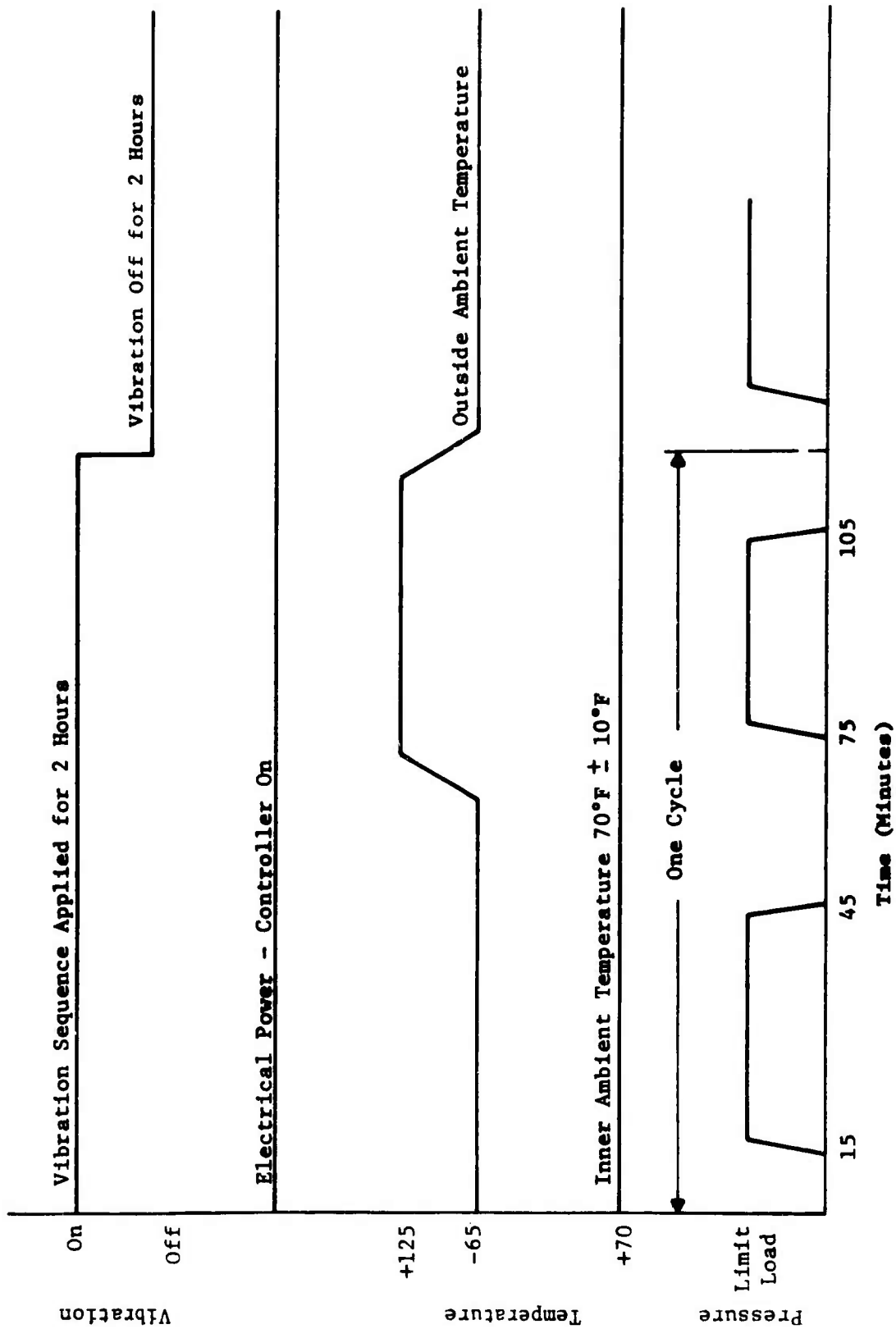


Figure 3. Life Cycle Test.

4.5 STRUCTURAL INTEGRITY

4.5.1 Pressure Test Criteria

- 4.5.1.1 Each transparency shall satisfactorily withstand a differential pressure loading of P_D at temperatures of 0°F , 75°F , and $130^{\circ}\text{F} \pm 5^{\circ}\text{F}$ for a period of 30 minutes.
- 4.5.1.2 At the maximum pressure load P_D , the maximum allowable deflection of the transparency shall not exceed the average thickness of the part and the stress as determined by strain gages shall not exceed one-half the normal working stress of the material. During the sustained maximum loading P_D , changes in deflections and stresses shall not exceed 10% of the original values.
- 4.5.1.3 The design pressure, P_D , based on current investigations, shall be 2.0 psi for forward-facing transparencies or 1.0 psi as per the following applicability list. In some cases, qualification of the lower design pressure requirements can be achieved by analytical analysis and similarity.

	<u>Design Pressure</u>	
	<u>1.0 psi</u>	<u>2.0 psi</u>
Class I	Type III, IV, V, VI	Type I, II
Class II	N/A	Type I, II
Class III	Type III, IV, V, VI	Type I, II

4.5.2 Concentrated Load Test Criteria

In addition to the requirement as defined by 4.5.1 each transparency as required by 3.4.2.2 shall satisfactorily sustain a concentrated load of 200 pounds distributed over an area of 1 square foot for a period of 10 minutes at $75^{\circ}\text{F} \pm 5^{\circ}$. Where possible, analysis and similarity can be utilized.

4.5.3 Pressure Test

The transparency shall be mounted and firmly attached by normal installation techniques to a fixture that simulates the aircraft frame. The fixture shall be so designed that both positive and negative differential pressure of P_D relative to the atmosphere can be imposed on the transparency. For each test at 2 psi, transducers or dial gages shall be mounted at the transparency center and other locations where major deflections are anticipated. Strain gages shall be installed at critical locations based on analysis or previous tests.

After referencing all indicating devices, the transparency shall be subjected to a negative differential pressure by creating a vacuum in the fixture chamber of P_D . Measurements shall be taken as a minimum at the beginning, middle, and end of each pressurized hold period. After a hold of 30 minutes, the pressure differential will be reversed by creating a pressure load of P_D in the chamber. This condition will be maintained for 30 minutes, after which the complete cycle will be repeated. Two complete cycles will be conducted for each temperature. Measurements during the second cycle shall be within $\pm 10\%$ of the first at any temperature. Upon completion of the test at all temperatures, the transparency shall be inspected for structural quality.

4.5.4 Concentrated Load Test

The transparency with strain gages attached at critical locations shall be supported by an appropriate wooden frame that simulates the aircraft structure. A dead weight load of 200 pounds contacting 1 square foot of the transparency shall be applied at the most critical location for 10 minutes. Stresses as calculated from strain gage measurements shall not exceed the normal working stress.

4.6 ABRASION RESISTANCE

4.6.1 Criteria

- 4.6.1.1 The exposed outboard surface of each transparency (and inboard as applicable) shall be capable of attaining an acceptable abrasion resistance limit when subjected to the Taber abrasion test. All materials shall as a minimum show an abrasion resistance equivalent to acrylic MIL-P-8184.
- 4.6.1.2 Each transparency with a highly abrasive resistance requirement as per 3.2 shall demonstrate superior performance equivalent to glass, when subjected to the Taber abrasion test.
- 4.6.1.3 Each Type I transparency as required by 3.2 shall show no evidence of surface damage when subjected to the wiper test as proposed by U. S. Army Mechanics Materials Research Center.

4.6.2 Abrasion Test

An abrasion test per Federal Test Method Standard 406, Method 1092 shall be conducted for each transparent material to determine the material's relative resistance to abrasion. The samples as tested need not be representative of the transparency design, but such samples must be subjected to all fabrication processes that could affect the surface of the material. Similarity and analysis can be utilized whenever possible.

4.6.3. Wiper Test

A wiper test as proposed by AMMRC shall be conducted for transparency as required by 4.6.1.3. Similarity can be utilized whenever possible. For actual tests, three flat 12 in. x 12 in. samples representative of the transparency shall, each in turn, be rigidly supported by a periphery frame. A moderate flow of tap water with dispersed abrasive consisting of AC Spark Plug Cleaner, 200-400 grit or equivalent, shall run continuously over the surface of the sample. A 7-in. hycar rubber blade attached to a Marquette motor through an appropriate gearbox applying to a pressure of .2 to .3 pound per inch shall sweep the wet surface of the sample at a rate of 50 to 150 strokes per minute. Two complete sweeps shall be considered one cycle, and a total of 4000 cycles is required for each sample. The test can be interrupted at 1000 cycle intervals for inspection if necessary. At the conclusion of the tests, all samples shall exhibit a performance comparable with glass, and no marks, scratches or other damage that would interfere with the vision capability of the transparency.

4.7 FAIL-SAFE CONSTRUCTION

4.7.1 Criteria

- 4.7.1.1 Each transparency as required per 3.8 shall be capable of withstanding the normal operating loads after the primary structural member has failed.
- 4.7.1.2 The remaining structural member of the transparency shall support a load of at least 1 psi for 15 minutes.

4.7.2 Test

- 4.7.2.1 The transparency shall be mounted to the test fixture using the same procedures followed for the production helicopter. Mounting gaskets and torquing procedures shall be established, or if they are already in existence, shall be used for this test. The test shall be conducted at ambient conditions with the inside and outside air temperature at $75^{\circ}\text{F} \pm 5^{\circ}$, and the heating system shall be energized with design power. Transparencies without anti-ice capability shall be tested at $90^{\circ} \pm 5^{\circ}\text{F}$. The power shall be applied until the temperature sensing element first turns off the power, after which the windshield shall be allowed to cycle on and off for 30 minutes. At this point, the full operating load of 1 psi shall be applied to the windshield. This may be either an external or internal pressurization, depending on the performance envelope for the helicopter. After the load

has stabilized, the primary structural member shall be fractured. Limited visibility through the transparency shall exist, and the load on the transparency shall be sustained for 15 minutes.

- 4.7.2.2 In cases where it is not possible to fracture the primary structural member during pressurization, the member shall be broken prior to pressurization. The imposed load shall be 25% greater than 4.7.2.1. If the anti-ice system is also rendered inoperable when the primary structural member is fractured prior to the test, the ambient temperature shall be $90^{\circ}\text{F} \pm 5^{\circ}$.

4.8 CRASHWORTHINESS

4.8.1 Criteria

- 4.8.1.1 Each transparency shall be so designed for safety consistent with the applicable requirements of 3.9 that representative 12 in. x 12 in. specimens with appropriate edging shall remain self-contained after all structural members are fractured by a falling ball of suitable energy sufficient to cause failure of all structural members, but not in excess of 100 ft-lb.

- 4.8.1.2 No separation of structural members, penetration, or cracking through the complete thickness is permitted. All particles dislodged from the surface opposite the impact shall be less than 1/4 in. in length.

- 4.8.1.3 Three specimens will be tested for each transparency and similarity utilized as applicable. Designs unsymmetrical through the thickness shall be tested with impacts of each surface.

4.8.2 Test

Specimens 12 in. x 12 in. representative of the transparency configuration with appropriate edging shall be fabricated. A total of three shall be required for each transparency with a symmetrical design. A total of six shall be required for unsymmetrical designs. The specimen to be impacted shall be supported horizontally on a rigid wooden frame with a 1-in. contact all around. A spherical steel projectile 5 to 10 lb in weight shall be dropped from a suitable height to cause fracture of all structural members. A maximum energy of 100 ft-lb shall be used. The projectile shall strike the specimen at the center. No cracking through the thickness or penetration shall occur, and all particles dropped from the lower surface shall be less than 1/2 in. in length.

4.9 BALLISTICS

4.9.1 Criteria

- 4.9.1.1 Each transparency shall conform to the requirements of 3.10 as applicable.
- 4.9.1.2 Tests shall be conducted on either full-size transparencies or representative 12 in. x 12 in. specimens. Whenever possible, particular transparencies shall be qualified on the basis of similarity.
- 4.9.1.3 Each transparency shall be capable of sustaining a differential pressure loading of one-half the design load (P_D) after experiencing a ballistic strike by the required projectile.

4.9.2 Ballistic Test

- 4.9.2.1 Unless otherwise specified, flat specimens 12 in. x 12 in. or larger representative of the transparency shall be used for ballistic testing. At least four samples shall be required for each transparency.
- 4.9.2.2 Each sample shall be mounted by a test frame similar to or more rigid than the actual intended mounting structure. Rear surface and edge support and the method of fastening the transparency will duplicate actual installation. A witness plate shall be suspended 6 in. behind the sample. Unless specified otherwise, tests shall be conducted at $70^{\circ} \pm 5^{\circ}\text{F}$ with the projectile impacting at 0° obliquity.
- 4.9.2.3 The specified projectile shall be fired from a suitable test weapon and its speed varied by changing the weight of propellant charge. Distance from the test weapon to the sample should be no greater than 30 ft. Speed shall be determined by two independent timing systems placed approximately 10 ft from the gun and approximately 10 ft from the target. The timing systems shall measure the actual time to traverse a distance of 10 ft.
- 4.9.2.4 After mounting the sample, an initial impact will be made at a velocity close to the expected ballistic limit for the sample. An inspection of the test sample and witness plate will be made to establish whether a complete or partial penetration occurred. A second sample will then be shot at a speed higher or lower than the first, depending on whether the first was a partial or a complete penetration respectively. This procedure should be repeated each time using a new sample until three complete penetrations and three partial penetrations within a speed range of 150 ft/sec have been achieved. The V_{50} ballistic limit can then be computed as the arithmetic mean of these six velocities.

4.9.3 Ballistic Fail-Safe Test

A full-size transparency shall be impacted with the required projectile and V_{50} limit velocity after which the transparency shall be fastened to the test fixture and subsequently tested according to the method as outlined by 4.5.2. The transparency shall be subjected to one-half the design pressure (P_D) as applicable and only one complete cycle.

4.10 ENVIRONMENTAL

4.10.1 Criteria

4.10.1.1 Satisfactory performance of each transparency shall be substantiated by tests per MIL-STD-810B or MIL-E-5272C.

4.10.1.2 Unless otherwise specified, representative samples shall be used and conformance achieved whenever possible by similarity and analysis. The specimens for the following tests shall be representative of the transparency cross section and measure 8 in. X 8 in. The specimen shall incorporate the complete edging design of the transparency and include all fabricating and machining operations. After each test as outlined by 4.10.2, the samples shall show no degradation such as delamination, crazing, moisture penetration, cracking, or any change in light transmission or haze exceeding 2% from the original value.

4.10.2 Tests

4.10.2.1 Relative Humidity

After inspection and appropriate measurements, three specimens shall be placed in a sealed chamber with the environment controlled at 120°F and 95% to 100% relative humidity in accordance with MIL-E-5272C, Procedure III. After 500 hours at this exposure, the specimens will be removed and examined for any deterioration.

4.10.2.2 Sand and Dust

After inspection and appropriate measurements, three specimens shall be subjected to the Sand and Dust test as required by MIL-E-5272C, Procedure I. The sand used in the test shall be "140 mesh silica flour" as produced by the Fenton Foundry Supply Company, Dayton, Ohio, or the Ottawa Silica Company, Ottawa, Illinois.

4.10.2.3 Salt Spray

Three specimens shall be subjected to the test as described by Method 811.1 of Federal Test Method Standard 151A. A 20-percent solution shall be used and the test shall be conducted for 200 hours. After testing, the specimens shall be rinsed with tap water to remove the salt deposits and inspected for evidence of deterioration.

4.10.2.4 Sunshine and Sulfur Dioxide

Three specimens shall be subjected to the conditions of the Sunshine test as described by MIL-STD-810B, Method 505, Procedure I with two exceptions. The atmosphere inside the test chamber shall be maintained at 10% sulfur dioxide by volume and the test conducted for a total of 100 hours.

4.10.2.5 Fungus

Three specimens shall be subjected to the Fungus test as described by MIL-STD-810B, Method 508.

4.10.2.6 Snow and Ice Crystal Impingement

Three samples shall be subjected to PPG's Blast Abrader Test.² After cleaning, samples shall demonstrate performance equivalent to acrylic MIL-P-8184 with no adverse degradation and an increase in haze not exceeding 2% from the original value.

4.11 CHEMICAL RESISTANCE

4.11.1 Criteria

Each transparency shall demonstrate acceptable resistance to the chemical solutions as listed per 3.19 with no evidence of attack, crazing, pitting, cracking, or loss of adhesion when tested in accordance with Federal Test Method Standard #6053. Analysis and similarity shall be utilized as applicable.

4.11.2 Test

The test as defined by Federal Test Method Standard #6053 shall be conducted on samples representative of the transparency with two exceptions. The chemicals as listed by 3.19 shall replace

²M. S. Tarnopol, SALT BLAST EROSION TEST FOR AIRCRAFT PLASTIC WINDSHIELDS, PPG Industries, Inc., Pittsburgh, Pennsylvania, presented at Conference of Transparent Aircraft Enclosures, 5-8 February, 1973.

benzene, and both the tension stress area and a neutral stress area shall be subjected to the chemical action.

4.12 BIRD STRIKE RESISTANCE

4.12.1 Criteria

- 4.12.1.1 Each transparency, as required by 3.11, shall be capable of sustaining an impacting 4-pound bird at a relative velocity of 200 mph or as otherwise specified without penetration and without any release of spall with high kinetic energy.
- 4.12.1.2 Penetration resistance shall be acceptable if there is no cracking, separation, or tearout which permits bird tissue to pass through or around the transparency. This shall be determined by visual inspection of the transparency, support fixture, and witness sheet.
- 4.12.1.3 Resistance to secondary particles (spall) shall be acceptable if no particles are ejected from the transparency with sufficient size or energy to become lodged in a .060 in. to .080 in. witness sheet placed 12 in. behind and parallel to the transparency (or, alternately, lodged in a dummy headform placed in the crew member's head motion envelope). This shall be verified by visual inspection and by touch when a hand is rubbed over the surface of the witness sheet (or headform).
- 4.12.1.4 Tests on full-size transparencies shall be conducted at an approved facility at ambient temperatures from 20°F to 120°F. A minimum of two tests shall be conducted per condition. Where applicable, transparencies can be qualified by similarity.

4.12.2 Test

- 4.12.2.1 The full-size, complete transparency shall be mounted in a section of the airframe or equivalent fixture sufficient to duplicate the response of the complete vehicle under bird impact. The mounting angle shall be the installation angle of the transparency in an aircraft in level flight.
- 4.12.2.2 The impact point shall be selected to establish the most meaningful evaluation of compliance. If no specific location is indicated, the impact point shall be at the geometric center of the impacted surface of the transparency.
- 4.12.2.3 The bird impact test shall be made with a complete whole 4-pound chicken (1836 ± 66 gm) restrained to form a reproducible "package". The bird shall be freshly killed or killed previously, immediately frozen, and completely thawed prior to the test.

- 4.12.2.4 The test facility shall be capable of firing a 4-pound bird accurately ($\pm 3\%$ of velocity, within a 1 in. circle on the target) with no yaw or tumbling. Velocity shall be determined by two independent timing systems which measure the actual time required for the bird to traverse a predetermined distance.
- 4.12.2.5 A witness sheet of .060 in. to .080 in. corrugated fiberboard shall be placed 12 in. behind and parallel to the test panel. Where spall is of secondary importance, a dummy headform will be placed in the crew member's head motion envelope in lieu of a witness sheet. The witness sheet (or dummy) shall be used to indicate the severity of rear face spall.
- 4.13 FLIGHT EVALUATION
- 4.13.1 Criteria
- 4.13.1.1 After each transparency has successfully demonstrated acceptable performance relative to all previous qualification tests, a flight evaluation shall be conducted. Three aircraft shall be fitted with at least one-half of a complete ship set of transparencies for flight evaluation.
- 4.13.1.2 The transparencies as installed shall be subjected to normal operating environment and mission profile at three separate and distinct locations as follows.
- 4.13.1.2.1 Moist, hot climate typical of southeastern United States or equivalent. The rain-removal system shall be in operation for at least 15% of the total operating time.
- 4.13.1.2.2 Dry, arid climate typical of far west United States or equivalent.
- 4.13.1.2.3 Extreme cold climate typical of Alaska or equivalent. The anti-ice/defog system shall be in operation for at least 10% of the total minimum operating time.
- 4.13.1.3 Normal mission profiles shall be utilized for each aircraft attaining an accumulated operating life of 300 hours per aircraft. If one aircraft is utilized at all three flight locations, the total accumulated operating life to substantiate qualification shall be 600 hours.
- 4.13.1.4 The aircraft shall be parked, when not in actual flight, in the open and consequently exposed to all climatic conditions.

4.13.2 Test

Each aircraft shall be flown per the normal mission profiles with the heating system controller "ON". At least 10% of the accumulated flight time shall be conducted in the hovering mode as applicable per mission profile. Total accrued time for each aircraft subsystem shall be documented. At least ten rapid descents shall be conducted for each test site with a maximum rate of fall from 15,000 to 1,000 feet above sea level. After completion of this flight evaluation, inspection shall be conducted to substantiate acceptable transparency performance. Where necessary, transparencies shall be returned to the supplier for acceptance evaluation per 5.0.

5.0

ACCEPTANCE TESTS

Acceptance tests and required inspection will be conducted on production parts to substantiate that each transparency conforms to the requirements of this specification. The following acceptance tests shall be conducted for each production part fabricated per this specification with all results documented. These tests shall be on a continuing and complete basis unless a sampling program is recommended for a specific requirement. All such tests shall be conducted at the fabricator's facility. Any failure to comply with the requirements of these acceptance tests shall constitute a cause for rejection.

5.1

ANTI-ICE/DEFOG ELECTRICAL CHARACTERISTICS

All electrical circuits and characteristics as required per 3.1.6 shall be inspected and tested to insure acceptable performance of the heating system. Each electrically heated transparency shall be tested. Any failure to comply with requirements shall be cause for rejection.

5.1.1

Bus to Bus Resistance

5.1.1.1

Criteria

5.1.1.1.1

The bus to bus resistance of each completed windshield shall be within $\pm 15\%$ of the nominal as specified by applicable drawings.

5.1.1.1.2

As applicable, the resistance of each phase of a three-phase heating system shall be within $\pm 10\%$ of the average of all three phases.

5.1.1.2

Test

The bus to bus resistance of each phase of each transparency shall be measured at $75^{\circ}\text{F} \pm 5^{\circ}$ using a suitable resistive bridge measuring device or equivalent.

5.1.2

Insulation Resistance

5.1.2.1

Criteria

Insulation resistance of each completed windshield assembly shall be capable of withstanding 2,200 volts rms at 60 cps without arcing or breakdown.

5.1.2.2 Test

5.1.2.2.1 The dielectric strength of the completed windshield assembly electrical connections shall be determined by applying 2,200 volts rms at 60 cps between the following points:

- a. Power terminals to sensor terminals
- b. Power terminals to exterior surface of electrically heated outer ply
- c. Power terminals to periphery of windshield

5.1.3 Temperature Sensing Element

5.1.3.1 Criteria

Each temperature sensing element shall conform to the specified temperature/resistance characteristics and shall be capable of withstanding 10 vac without any detrimental effect.

5.1.3.2 Test

5.1.3.2.1 The resistance of the temperature sensing element of each completed windshield assembly shall be measured and recorded with the ambient temperature at the time of the measurement. The measured resistance shall be in accordance with the specified temperature/resistance characteristics.

5.1.3.2.2 Ten volts ac shall then be applied to the sensing element for a period of 15 seconds, cut off momentarily and reapplied until 3 on-off cycles are completed. After the temperature of the sensing element has returned to ambient, a minimum of 5 minutes, the resistance shall again be measured.

5.1.4 High Gradient Hot Spots

5.1.4.1 Criteria

Each electrically heated transparency shall be free of high gradient hot spots caused by heating film defects, scratches, or nonuniformity.

5.1.4.2 Test

Each transparency shall be vertically positioned between cross polaroid light system sufficient to include the entire vision area or daylight opening. After noting all regions of localized birefringence, the conductive film shall be energized with 150% design power to raise the transparency to operating temperature. All areas of localized high birefringence or concentrated color changes shall be marked for inspection.

5.1.5 Heated Area

5.1.5.1 Criteria

Location of bus bars, isolation lines, temperature sensing elements, and terminal blocks shall be inspected.

5.1.5.2 Test

All physical characteristics of the heated area shall be verified by inspection and measurements as applicable.

5.1.6 Heating Uniformity

5.1.6.1 Criteria

Each windshield assembly shall uniformly heat, attaining design operating temperature $\pm 10^{\circ}\text{F}$ when operated with design voltage.

5.1.6.2 Test

5.1.6.2.1 Each completed transparency shall be powered with nominal operating voltage and allowed to cycle at design operating temperature with the temperature sensing element connected to a suitable electrical controller. Temperature of the outboard surface shall be determined using thermocouples bonded to the windshield surface or other calibrated and dependable temperature contact sensitive devices. After determining the relative correspondence between the outboard surface temperature and K-values, an alternate test as outlined by 5.1.6.2.2 can be utilized. The test shall be conducted in still air at $75^{\circ}\text{F} \pm 5^{\circ}\text{F}$ and measurements shall be made within 10 minutes after starting the test.

5.1.6.2.2 The power constants of the conductive film shall be determined before lamination according to the conventional power constant procedure. The transparency outboard member shall be supported horizontally with the conductive film exposed. The conductive film shall be energized with design voltage and electrical power input measured. After a thermal stabilization of at least 1 minute, the temperature difference through the thickness at the hot spot and control point shall be measured with paired thermocouples or equivalent exactly opposite each other. After calculating the average power density, the power constants K_h , K_a and K_m shall be calculated and conformance ascertained with respect to the specified limits.

5.2 THERMAL SHOCK

5.2.1 Criteria

Each transparency as required per 3.1 shall be capable of functioning and satisfactorily withstand the thermal shock associated with operation of the heating media at -65°F . If the first 20 parts of a particular transparency design, inclusive of either hand if symmetrical, achieve successful performance without deterioration, a sampling procedure as defined by 5.8 may be initiated.

5.2.2 Test

As outlined by 4.3.3 except only 1 cycle shall be required.

5.3 OPTICAL QUALITY

5.3.1 Distortion

5.3.1.1 Criteria

5.3.1.1.1 Each transparency comprising a portion of the cockpit enclosure shall demonstrate acceptable optics with no abrupt bending or objectionable blurring of the grid image viewed through the primary vision area.

5.3.1.1.2 Each transparency shall have as a minimum the grid line slope as defined by 3.3.1.2 when tested in accordance with the test as outlined by 5.3.1.2.

5.3.1.1.3 The test as outlined by 5.3.1.2 is applicable on a continuing basis for all Grade A and B areas of each transparency as detailed by this specification. Conversely, transparencies with Grade C optics only can be tested on a sampling basis as outlined by 5.8.

5.3.1.2 Test

Optical distortion shall be evaluated by determining the maximum slope of a deviated grid line from a print made by photographing a grid board through the transparency. The transparency shall be mounted in a fixture and oriented to simulate the location of the part relative to the pilot's vision line when installed in the aircraft. The distance from the grid to the center of the panel shall be 10 feet. The camera shall be located with the lens at the pilot's eye position relative to the installed panel. A single exposure of the grid shall be made through the panel. Zones as designated by the

transparency location and vision requirements shall be outlined on the surface of the part. The panel shall be identified with at least the date, part number, and serial number of transparency which shall appear on the photograph.

If the total area of the transparency cannot be covered with one photograph, the panel shall be moved and additional photos taken. The pilot's vision angle to the part as installed shall be maintained for all areas photographed. Glossy prints (8 in. x 10 in.) shall be made of the grid photographs.

The prints shall be examined for distorted grid lines and grid slope measured in the most severely distorted areas. The slope shall be determined by aligning a straightedge tangent to the curve of the grid line in the most severely distorted area and counting the number of undistorted grids crossed in one direction before crossing a single grid at a right angle to that direction.

5.3.2 Optical Defects

5.3.2.1 Criteria

5.3.2.1.1 No major optical defects shall be present in the primary vision area of each transparency. Such major defects shall include cracks, chips, deep scratches, crazing, and V edge chips. Also, any minor optical defects so grouped as to cause distortion or visual distraction shall be classified as major defects.

5.3.2.1.2 Minor optical defects within the vision area of each transparency shall not exceed a total maximum average of three defects per square foot. Such defects shall not be so grouped as to cause objectionable distortion. Minor optical defects shall include small, opaque inclusions, bubbles, seeds, blisters, and surface pits or dimples that do not exceed a maximum length of .125 in., and surface scratches that do not exceed a depth of .005 in. and a length of 3 in. All such defects shall not affect the structural integrity, and actual tests of representative samples shall show a reduction that does not exceed 10% of the basic material strength.

5.3.2.2 Test

Each transparency shall be examined for optical defects by viewing against a dark background illuminated by blue-white fluorescent lights, or equivalent, sufficient to distinguish small defects. The transparency shall be positioned vertically and located approximately 5 to 10 ft from the viewing background. The inspector shall vary his location from the transparency as necessary to thoroughly inspect the part. A

distance of 1 to 3 ft is recommended. All defects detected shall be marked on the transparency and documented. Where necessary, an optical comparator shall be used to measure the size of small defects near the allowable limit.

5.3.3 Light Transmission

5.3.3.1 Criteria

5.3.3.1.1 Original minimum light transmission for each transparency as defined by 3.3.3 shall be 70%.

5.3.3.1.2 Light transmittance shall be measured on a continuing basis for each Type I and II transparency, whereas a sampling program as outlined by 5.8 may be utilized for each Type III and IV transparency.

5.3.3.2 Test

The luminous transmittance of each transparency shall be determined in accordance with Method 3022 of LP 406. An illuminant C light source or equivalent shall be used. Measurements shall be made at five different locations at least 6 in. apart for each transparency. One measurement shall be made at the geometric center of each transparency and the others at the approximate center of each edge some 4 in. to 8 in. inside the edging material. All readings shall be documented.

5.3.4 Haze

5.3.4.1 Criteria

5.3.4.1.1 Original maximum haze for each transparency as defined by 3.3.4 shall not exceed 4%.

5.3.4.1.2 Haze shall be measured on a continuing basis for each Type I and II transparency, whereas a sampling program as outlined by 5.8 may be utilized for the remaining types as applicable.

5.3.4.2 Test

A Gardner pivotable sphere haze meter, or equivalent, shall be used. Four measurements shall be made at locations at least 8 in. to 10 in. apart. Where possible, haze determinations shall be made at areas where light transmission was measured. All values shall be documented.

- 5.4 STRUCTURAL INTEGRITY
- 5.4.1 Criteria
- 5.4.1.1 The structural integrity of each transparency shall be verified, on a continuous or sampling basis as specified, showing no adverse effects or out-of-control condition caused by the fabrication process.
- 5.4.1.2 Conventional structural quality and adhesion tests in accordance with the material specification or standard practice shall be conducted on coupons completely representative and accompanying the transparency throughout the process. The specific values as determined for the fabricated transparency on the basis of the coupons shall be within the specified limitations.
- 5.4.2 Test
- The following nondestructive tests of full-size transparencies and destructive tests of coupons shall be conducted as applicable.
- 5.4.2.1 Thermal Temper
- The degree of strengthening glass or equivalent material by thermal tempering shall be determined by measurement of the residual tension in the central plane or surface compression of the full sized structural members. Measurements shall be made utilizing the conventional method per MIL-G-25667 or equivalent.
- 5.4.2.2 Surface Toughness
- The surface strength of acrylic, polycarbonate or equivalent shall be determined by conducting the appropriate test per MIL-P-25690 or MIL-P-83310 or equivalent as applicable on 2-in. x 8-in. sample coupons.
- 5.4.2.3 Adhesion
- 5.4.2.3.1 The bond of structural edging or protective layers shall be substantiated by inspection and nondestructive test as applicable.
- 5.4.2.3.2 The quality of adhesion of structural members, protective layers and edging shall be substantiated by appropriate peel tests as applicable.

5.5 INTERCHANGEABILITY

5.5.1 Criteria

Each transparency on a continuing basis shall be checked with a master gage, fixture, or equivalent to ascertain the dimensional conformance. The tolerance limits per applicable groups follow.

	<u>Type I, II</u>	<u>Type III, IV, V, VI</u>
a. Size	± .125 in.	± .125 in.
b. Surface contour	± .175 in.	± .250 in.
c. Edge contour	± .125 in.	± .200 in.
d. Thickness	± 10%	± 10%
e. Bolt hole size	± 5%	± 5%
f. Weight	± 5%	± 5%

5.5.2 Test

5.5.2.1 Thickness

The thickness of the transparency edging shall be measured to the nearest thousandth of an inch with a micrometer. Measurements shall be taken along the hole centerline at 6-in. intervals around the transparency periphery.

5.5.2.2 Weight

Each transparency shall be weighed on a calibrated balance. The weight shall be recorded to the nearest one-tenth of a pound.

5.5.2.3 Hole Size

All hole diameters shall be checked with the appropriate go-no-go gages. Any holes beyond the limit shall be measured and documented.

5.5.2.4 Edge Contour

The transparency shall be positioned on appropriate male fixture or equivalent and held in place by tapered pins through the middle hole of each edge. All regions of severe deviations between the contacting surface of the fixture and edging shall be noted and measured with a thickness gage. A total gap of two times the tolerance figure is the maximum permitted.

5.5.2.5 Surface Contour

With the transparency positioned and held in place as per 5.5.2.4, the contour across the surface shall be inspected for any sharp or severe discontinuities.

5.5.2.6 Hole Alignment

With the transparency in position as per 5.5.2.5, apply clamps with suitable contact bumpers as necessary to bring all edging down to the surface of the fixture. Care should be used not to overload the edging. The appropriate pin with a diameter corresponding to the nominal bolt size shall be used to check hole alignment. This pin shall freely pass through each combined hole of the transparency and fixture.

5.5.2.7 Size

With the transparency in position as per 5.5.2.6, the size shall be checked relative to the fixture scribe line. Any oversize condition shall be reworked.

5.5.2.8 Inspection

The transparency shall be examined for delamination, chipping, cracking, or any other deleterious effects.

5.6 VISUAL REFLECTION

5.6.1 Criteria

Each transparency, as required per 3.17.2 shall have a maximum light reflection in the visible range not exceeding 1% per surface.

5.6.2 Test

Light reflection measured by glossmeter or equivalent.

5.7 RADAR REFLECTIVITY

5.7.1 Criteria

Each transparency as required per 3.23 shall have a radar reflective film of 15 ohms per square.

5.7.2 Test

The bus to bus resistance shall be measured in accordance with 5.1.1.2.

SAMPLING PROGRAM

Tests as defined by 5.0 shall be conducted, where applicable per the specific criteria, for one out of every five panels of similar design. In the event, of failure or deterioration of the panel sampled, 20 consecutive transparencies of a particular design shall be successfully tested before sampling can be resumed.

DISCUSSION OF DESIGN SPECIFICATIONS

The detailed and complete specification for rotary wing aircraft is associated with actual aircraft mission and transparency function. The actual requirements are optimized relative to all objectives. The actual rationale leading to the requirement with associated tests that should solve the apparent problems are detailed in this section.

ANTI-ICE/DEFOG

The specification recommends that all Type I and some Type II forward-facing windshields on all helicopter classes have an anti-ice/defog system, thereby attaining all-weather capability. Of the various existing helicopters surveyed during the preliminary study, only the CH-54, UH-1, OH-6, and OH-58 aircraft did not have any means of anti-ice/defog capability (Appendix I). Conversely, 73% of the answers were yes to the survey question of the anti-ice requirement for windshields (Appendix III, Interviews, Question 5). As a result of these findings and the obvious advantage of maintaining clear vision, it is recommended that anti-ice or defog as a minimum be a primary design requirement of forward-facing windshields, even though all-weather capability is not a mission requirement of the total fleet. Thus, it would thereby require anti-icing of other critical areas such as engine inlets, rotor blades, and control surfaces.

Of the various methods available for anti-icing (electrical, hot air, chemicals), the specification addresses electrical methods because this technique is the most efficient, is now widely used in fixed-wing aircraft and, is an integral part of the windshield design. Alternate methods such as hot air and chemicals are implied by reference to MIL-T-5842A, but no detailed specifications or discussion are presented since this would be considered a system external to the windshield.

Failure of the windshield anti-ice/defog system with associated effects such as delamination, bubbling, cracking, etc., as found to be a major problem of existing windshields surveyed during the preliminary study. The specification details electrical and heating film requirements essentially consistent with existing industrial specifications for electrically heated windshields. A worthwhile consideration to extend the life of the transparency is the addition of an extra temperature sensing element (TSE).

Information collected during the preliminary study indicates that glass-faced windshield designs have fewer heating film failures than the electrically heated plastic windshields. The UH-2 windshields, which have a conductive film applied to the outboard glass ply, did not report any heating system failures as compared with the all-plastic windshields used in the CH-47 and CH-53 (Appendix III, Tables 38, 40, and 53). It is believed that this difference is primarily due to the relatively soft

coatings and lower adhesion associated with plastic substrates. Although this may be the case, either windshield design can effectively be manufactured per the same electrical specifications. For this reason, three qualification tests to specifically verify the windshields heating film system have been incorporated into the actual specification.

The cyclic test as defined by 4.2 and the thermal shock test as defined by 4.3 are incorporated to verify basic materials and designs during operation of the heating system under simulated environmental conditions. The additional Life Cycle Test, as defined by 4.4, subjects the windshield assembly to the combined effects of pressure loading, vibrational loading, thermal loading, and environment. It is anticipated that this test will subject the windshield to mechanical and thermal stresses and deflections that would normally be encountered in actual use.

The acceptance tests as specified per 5.1 verify basic electrical characteristics, thus insuring proper interface and compatibility of the windshield assembly within the aircraft's electrical system. Additional tests verify operation of the temperature sensing element and evaluate the heating film for defects.

RAIN REMOVAL

Consistent with the anti-ice/defog capability specified for all forward facing windshields, a suitable rain-removal system shall be provided. The reasons are quite similar. Existing helicopters mainly rely on a windshield-wiper system to provide clear vision through rainfall. As determined in the preliminary study, the wipers caused considerable damage to the plastic-faced windshields. Nevertheless, windshield wipers are a reliable, effective, and readily available rain-removal system.

Alternate methods of rain removal are hot air blast or chemical rain repellent coatings. The hot air blast consists of directing a high velocity stream of hot air over the external surface of the windshield via a duct outlet positioned at the base of the windshield. This system is effectively used on fighter fixed-wing aircraft which typically have small flat center windshields when compared to the much larger and usually curved windshields associated with helicopters. Other problems associated with the hot air blast are temperature regulation and air volume availability necessary to effectively cover the large windshield areas. The AH-1G uses hot air blast and has encountered cases where the windshield was distorted or melted because of excessive temperature of the air (Appendix III, Table 55).

Chemicals could either be applied while on the ground, or the aircraft could be fitted with a supply tank and dispersion system to be applied during flight. To date, no chemical rain repellents are effectively used as a standard and proven system on any aircraft. The probable reasons for this are the inherent shortcomings of this type of system such as the effective life of each application with a need to reapply the coatings, and the cost and weight for a pilot-controlled flight dispersion system.

The proposed specification has been optimized to a certain extent in that section 3.5 specifies that the outboard surface of Type I windshields be highly abrasion resistant to damage encountered during wiper operation. This requirement plus the use of proper maintenance procedures as specified in Appendix IV (Preventive Maintenance Procedures, Windshield Wiper) will allow the continued use of wiper systems without the associated detrimental effects to the transparency.

OPTICAL QUALITY

The same general comments as stated in Appendix III (Failure Mode Description, Distortion) would provide the reasoning and rationale for the optical requirements as specified in 3.3. Distortion problems revealed during the preliminary study were consistently related to other failure modes such as scratching, delamination, and overall deterioration of plastic transparencies. The optical properties of existing windshield designs and other transparencies are satisfactory and within accepted limits per type of aircraft application. The proposed specification requirements, including acceptance test methods and criteria, are in accordance with existing industrial specifications. The specification does not differentiate optical requirements as to helicopter class, but it is recognized that as more sophisticated weaponry and optical guidance systems become incorporated into the Class II Attack helicopters, modification will be necessary.

STRUCTURAL INTEGRITY

The initial design objective of "fracture resistance" has been revised to "structural integrity", because such a term is more meaningful and complete.

Although transparencies in helicopters are not designed as actual structural members, they are subjected to loads during operation and maintenance, and to exposure to the natural and human environment. Breakage was one of the main causes of replacement as determined by the preliminary study. Although this failure mode prevailed for all transparencies regardless of materials and design, glass laminated structures tended to show a higher concentration per all failure types of a given helicopter. All failure modes experienced for the UH-2 glass windshield were breakage types, as shown by Appendix III, Table 53. Although Appendix III, Table 44 showed a high concentration of breakage for the UH-1 windshield which required replacement, other reasons for failure were of similar magnitude.

Normally, forward-facing transparencies such as windshields are required to sustain differential pressure loadings related to the lift system and speed of the helicopter. Such limit or operating loads are of the order of 1 psi on the windshield and are likely of lower magnitudes on the lower and upper windows. No pressure loading of any significant magnitude is typically experienced by the side windows within the cockpit or cabin. Nonetheless, to substantiate the structural quality, appropriate test criteria of all transparencies require a pressure test at twice the limit loads. An

auxiliary requirement to specify some degree of load-carrying capability that would simulate a man stepping on an upper window is now required. Both of these tests as applicable are required to qualify a transparency design. The addition of sensing devices is included to better understand the transparency performance, and the hold periods of sustained loads can produce failures that quick loadings would not. It does not seem unreasonable that loads in service, especially the differential pressure type, could occur for extended times.

The production tests as detailed by 5.4 substantiate the inherent quality of the transparency. Nondestructive checks are required as possible, but the majority of the tests will be performed on coupon(s) that accompany the part through the fabrication process. Hence, the effect of the process shall be determined and control maintained on the transparency.

ABRASION RESISTANCE

The relative abrasive resistance of plastics does not approach that of glass-type materials, but monolithic plastic such as acrylic is less costly and somewhat safer than monolithic glass. Also, plastic material is easier to mold to exotic shapes and is lighter than glass. Hence, acrylics per MIL-P-8184 have been widely used throughout the rotary-wing aircraft industry. The preliminary survey indicated that abrasion or scratches were the most common and widespread reason for replacement. This type of failure consistently prevailed for plastic type panels, both acrylic and polyester, with rain wipers.

Sixty one percent of the responding personnel rated scratches as the primary problem for windshields. This problem was judged to be 6 times as prominent as the second most prevalent modes: distortion and mistreatment. However, per Appendix III (Interviews, Question 1) these two modes could also be the result of scratches, since rework of the scratched area removes some of the scratch and subsequently, distorts vision. Also, according to Appendix III (Summary of Questionnaire 6) scratches are "lived with" in the field and scratches are also a major problem on other windows. Conversely, glass-faced windshields exhibited a minor amount of scratch problems. For comparison, refer to Appendix III, Tables 39, 42, and 44, for plastic windshields and Tables 43 and 53 for glass laminated structures.

The specification proposed by this study addresses some degree of abrasion resistance for all transparencies, but the criteria do not eliminate the use of acrylic. Since scratches on the majority of windows not considered primary for vision are functional, it appears reasonable for the specification to continue the use of acrylic material. However, for the main windshields, this specification requires the use of glass or equivalent material for all outboard surfaces with wipers. This stipulation will result in an aircraft with complete conformance to all-weather capability as well as extend the life of the windshields.

The abrasion resistance of materials must be substantiated by actual qualification tests using the Taber abrader. Although this test has shortcomings, it can suffice to evaluate new materials. This technique thus infers that harder materials will have better abrasion resistance.

No wiper test is now accepted as the industry standard, since such tests are difficult to define and repeatability is of major concern. Some recent tests have proposed wiper operation dry. This test would be difficult to conduct because of skipping, applied load problems, and repeatability. Earlier tests as conducted for the CH-47 and CH-46 were repeatable but not realistic. Although the plastic-faced material sustained 900,000 cycles of a wiper with continuous water, service showed many scratches from wiper operation. Consequently, a wiper operating on a wetted surface with some abrasive particles would represent a possible test. Such a test is specified by 4.6.1.3. This test as proposed by U.S. Army Mechanics Materials Research Center, Watertown, Massachusetts, meets these conditions, but actual experience and any correspondence to actual service remain to be established.

RELIABILITY

Reliability is usually interpreted as the satisfactory performance of a transparency according to design without failure or malfunction. Therefore, a properly designed transparency per ideal and accurate specifications would achieve the required reliability.

As discussed in Appendix III, Replacements, many different methods have been devised to measure the degree of reliability - MTBRR, MTBF, MTR. However, all methods tend to be dependent on documentation which costs money and requires human efforts. The first two methods (MTBRR and MTBF) require extra bookkeeping, since the hours of the fleet of a certain size must be recorded. This would not be a difficult task if aircraft were stable relative to a particular base. Because of all such inherent problems with these methods, the proposed specification addresses reliability on the basis of shelf, useful, and operating life as defined by 3.6.1. An actual warranty is specified relative to particular transparencies. Actual service will demonstrate the achievement of reliability.

THERMAL SHOCK RESISTANCE

Industrial specifications of windshields with electrical heating films have specified thermal shock tests to verify the functional quality of the heating system. These tests have shown some variation between voltage applied, soak temperature, ambient test temperature, and actual cycles. Probably the most damaging aspect of these variations was the use of over-power. Although this type of test could be used for qualification, over-power of heating film is not a good practice for acceptance of production tests. Therefore, the thermal shock test as defined per 4.3.3 shall be conducted with nominal voltage in both qualification and acceptance tests.

This test will be utilized to evaluate the coating as well as adhesion and structural quality. This test will isolate transparencies with poor adhesion to the conductive film.

An additional, general test for all transparencies to verify qualification status is proposed. This test will demonstrate acceptable exposure to temperatures of -65°F and $+160^{\circ}\text{F}$. The cyclic temperature variations of qualification will show any fundamental weaknesses, such as minute vents, etc.

FAIL-SAFE CONSTRUCTION

Fail-safe operation implies that a secondary load path be incorporated into the transparency construction in the event that the primary structural member becomes inoperative. A degree of fail safety is now inherent to acrylic, but not by design. Some levels of load can be sustained by acrylic that has cracks. However, this type of fail-safe construction has no safety aspects, since the actual load necessary to cause the crack to run is unknown. Since fail safety is not a requirement across all transparencies, the proposed specification addresses fail-safe construction for windshields only.

An additional desirable feature for each pilot would be residual vision after a primary structural member fails. One method of doing this for particular energy levels is by a controlled temper in glass.

Actual tests for this requirement are completed by qualification of a full-size part.

CRASHWORTHINESS

Aspects of safety as applicable have been considered at times, but general considerations are lacking. The primary concern is that the fractured transparent material shall not become a lethal weapon and be injurious to the crew. The fundamental requirement of this specification is that all fractured particles remain in the envelope of the transparency. A qualification test using a falling ball as defined by 4.8 will impose lamination of some sort for all brittle materials. Although the specification requires crashworthiness for all transparencies, it is a major consideration for the windshield.

BALLISTICS

Since all helicopters are considered as part of the Armed Forces arsenal and are thereby subject to combat environment and operation, a general ballistic requirement is addressed by this specification. This requirement in most cases was part of the existing industrial specifications. It is primarily aimed at preventing the use of brittle materials that would shatter or release large fragments when impacted.

In addition to this general requirement of minimum or no spall being released that would be injurious to the crew, a special requirement (3.10.2) for transparent armor is included. The primary objective of the special requirement is to defeat the projectile and thereby provide ballistic protection to the crew. The specification presented is not complete due to the classified nature of ballistic information and also to the multitude of ballistic parameters, such as projectile, range, and obliquity. The armor protection is considered to be a special requirement only, and the applicability table is intended to show logical areas of intended use. The specification is not optimized with respect to transparent armor requirements, and the suggested weights as given in 3.13.2 that relate to transparent armor are general guides and do not relate to any particular ballistic threat. Qualification testing as outlined in 4.0 is required, and standard approved testing methods would apply.

BIRD STRIKE RESISTANCE

Bird strike resistance, although not considered as a major problem to existing rotary-wing aircraft, is a potential threat to future generation helicopters, especially as airspeed is increased and operational noise levels are decreased. The requirement as stated in 3.11 would provide bird strike protection on all forward-facing windshields. For the present it is recommended that this performance requirement be a secondary design objective. Past experience has shown that the number of bird strikes on helicopter transparency areas is not of the same magnitude as on fixed-wing aircraft.

Even though bird resistance is a secondary requirement, it is recognized that a certain degree of bird resistance can be achieved. The qualification tests as specified in 4.12 would verify the level of impact resistance for particular designs.

VIBRATION RESISTANCE

Many different approaches have been utilized in the past to evaluate the vibration resistance of transparencies. Tests which included tie-down vibration or flight evaluation have been used. Actual vibration tests have been required by fixed-wing specifications and some of the latest helicopter specifications. However, the major problem has been to show the validity of such laboratory tests.

The proposed specification defines a vibration test within the structure of the life cycle test for windshields with electrical films. In this test the transparency will be subjected to various cycles of heating, pressure, and vibration. Finally, a flight test is required.

WEIGHT

Designs consistently strive for lighter constructions to increase the payload. However, modifications at later dates can cause extensive

adjustments in actual aircraft structure. Hence, it is certainly sensible to properly and realistically define the requirements at the beginning of the program.

The proposed specification requires that the weight shall be a minimum consistent with this specification. Hence, the realistic maximum limits on the basis of aerial density per transparency are specified. Appropriate adjustments are defined for special designs with bird proof and ballistic capabilities.

INTERCHANGEABILITY/INSTALLATION AND REMOVAL

As shown by the preliminary study installation and removal of transparencies was an area of major concern to helicopter users, especially the maintenance groups. It was revealed in many cases that maintenance actions were dependent on the complexity and type of installation method. The proposed specification requires that all transparencies be designed for interchangeability. It is believed that the transparency manufacturer can perform the required machining operations such as drilling and trimming to overall size much more efficiently and with better quality than field service maintenance personnel. Also, some of these operations such as drilling and machining are critical to certain plastic materials and require a certain amount of skill and specialized equipment. The specification also attempts to standardize the type of weather seal utilized for transparency glazing. Incorporation of the interchangeability requirements as specified in 3.14 into the basic design of helicopter transparencies will allow for more standardized maintenance procedures and reduce removal and installation time. The appropriate production tests are detailed for actual part acceptance.

MAINTENANCE

The preliminary study (Appendix IV) indicated that maintenance of a preventive nature was not well documented in required manuals, although the repair type maintenance was well covered. Hence, this specification proposes that these type documents (especially of the preventive category) be available before the part can be placed in service. In addition, it is specified that these special procedures be kept at a minimum.

VISUAL REFLECTIONS

Visual reflections can be divided into three separate areas of interest as related to transparency design objectives. The first is visual reflections from the interior surface of the windshield of an object within the cockpit. This type of reflection is more distracting at night. An example would be the reflection of instrument lights from the interior surface of the transparency. The second type of reflection that can be distracting to pilots, especially during night flight, is multiple images, which are reflected images from each surface, both external and internal within

laminated transparencies. This phenomenon tends to magnify any reflections from sources inside the cockpit and also reduces the resolution of external surface such as runway lights. The third effect is reflected light from the external surface that signals the enemy. All three types of reflections are associated with the index of refraction difference between the transparency and air. Both the internal reflections and multiple image effect were determined during the preliminary study to be secondary problems associated with existing helicopters. Accordingly, visual reflections are specified as a secondary design objective in the proposed specification. The external detection type of reflection can be considered as a possible requirement for future helicopters, especially with the increased attention given to survivability techniques and requirements. No requirement is stated in this specification for external reflectance values.

It is worthy to mention that existing materials and state of the art would prohibit achieving the requirements of 3.17 and that further investigation of this problem is required. Discarding such methods as etching, which creates a diffuse surface and detracts from the optical qualities of the transparency, the sole available method is low-reflection coatings. (The term "antireflection" is considered to be a misnomer in that coatings are able to reduce the percent of light reflected only for specified wavelengths and angles of incidence.) Existing low reflection coatings are relatively soft, especially when applied to plastic substrates because of the low application temperature. Therefore, such coatings would conflict with the general abrasion resistance requirements of 3.5.1.

ENVIRONMENTAL

Transparencies on helicopters are exposed to many different operational and nonoperational conditions associated with worldwide extremes of climate, weather, and fungus. The proposed specification addresses these possible exposures with a definition of required laboratory tests. These tests conducted for qualification are the fundamental laboratory conditions that should be used as the initial evaluation basis of a new design. The majority of the laboratory tests as defined by 3.18.2 are standard types, used repeatedly throughout the aircraft industry.

The actual tests as described by 4.10.2 are patterned after the military standards. A combination of sunshine and sulfur dioxide exposure presents a new type test that will yield an evaluation of interlayer adhesion.

The other new test devised by PPG Industries evaluates the effect of ice crystals. This test simulates ice crystal marring of polycarbonate and verifies the validity of hard coat for protection of polycarbonate. No test is proposed to simulate exposure to heavy rain on a sample, but some exposure of the final assembly is required in the flight test as defined by 13.0. It is rationalized that a rain exposure of samples would not produce effects beyond those caused by a 100% relative humidity test. Also, erosion type effects with water would require high velocities, and the equipment would be costly on the sample basis.

CHEMICAL RESISTANCE

The proposed specification establishes the chemical resistance of transparencies glazed in helicopters. The actual chemical solutions as defined by 3.19 are consistent with standard requirements. However, this specification only specifies a load under test as necessary and not both loaded and unloaded effects.

LIGHTNING STRIKE RESISTANCE

Lightning strike resistance has been specified because of the increased number of helicopter flights under instrument conditions. Helicopters are unique and quite susceptible to structural damage because of light-weight construction with increased use of nonmetallic structure. Also, primary flight profile of these aircraft is within the altitude of 2,000 to 12,000 ft where 80% of the strikes are reported. Although primary design considerations against lightning strikes are concerned with fuel systems and rotor blades, there is also the potential hazard of lightning puncturing the windshield and striking the pilot. Even though the probability of lightning striking the pilot is remote, this specification proposes the use of a metallic member around the transparency to prevent the lightning streamer from attaching to and subsequently puncturing the windshield.

No qualification test is specified for this requirement because of the effect of the surrounding structure and components, and it is, therefore, not considered to be a function of windshield design.

FIRE RESISTANCE

The proposed specification is consistent with standard requirements for fire resistance. Since no problems were detected during the preliminary study for this requirement, no modifications for this objective were necessary.

STATIC DISCHARGES

Static charges can be built up on the exterior surfaces of transparencies. These charges either discharge through the outer ply of heated windshields to the heating film or shock ground personnel after the aircraft has been parked for some period of time. The preliminary study has not shown this to be a problem, but it is a well-documented and investigated area for fixed-wing aircraft transparencies. The static charge is built up by flying through particular atmospheric conditions producing a bound charge on the transparency surface. Effects on electrically heated plastic transparencies are particularly troublesome because of the high surface resistivity of plastic materials, i.e., 10^{16} ohms/square for stretched acrylic. The high surface resistivity values allow potentials as high as 300,000 volts to be built up on the windshield with subsequent discharge to the metallic heating element that punctures the structure. Glass has a surface resistivity of approximately 10^{12} ohms/square, but it

has been determined that a surface resistivity value of 10^8 ohms/square would allow static charge to drain from the windshield surface and not build up to dangerous limits. As shown above, the surface resistivities of existing materials are not within the limits as specified, but the design requirement can be met with the use of electrically conductive films. The major limitation is that no existing antistatic coatings are durable when applied to plastic substrates because of the low application temperature resulting in soft film. Conversely, antistatic films are used successfully when applied to glass substrate in various fixed-wing aircraft.

Again, the specification has not been optimized in that the addition of extra conductive films such as heating films, radar reflective films, and antistatic films would reduce the light transmission requirement of 3.3.3.

RADAR REFLECTIVITY

Radar reflectivity requirements for attack helicopter windshields are specified in 3.23 because the cockpit areas of aircraft are a major source of radar signal returns. Depending on mission requirements of future helicopters, radar reflectivity can be achieved by the addition of an electrically conductive low resistivity film. This film scatters the radar signals in such a manner that detection of a helicopter by radar would be minimized. Such a requirement exists for some high performance fighter aircraft. However, the proposed specification considers radar reflection as a secondary design objective because of the ability of rotary-wing aircraft to maneuver at relatively low altitude, thereby penetrating enemy defenses below the radar net.

HEAT TRANSFER

The preliminary study (Appendix III) indicated that some environmental problems were associated with solar heating of the cockpit interiors. The small confines of the smaller observation and attack helicopters were readily heated by the sun. There were actual cases where doors were removed from the cockpit of the OH-6 to eliminate the "greenhouse" effect and gain some degree of cooling during flight. Therefore, the proposed specification addresses the need for heat absorbing transparent materials for the windshield and upper windows of the observation class of helicopters. The close quarters of the attack version tend to indicate the need for air conditioning, which certainly dictates heat absorbing transparencies.

Although requirements are detailed for this objective, no tests are proposed since the conformance can be accomplished by engineering analysis.

LIFE CYCLE COST

Although life cycle cost was listed for consideration in the statement of the work, it is not addressed in the proposed specification. The specification does define the operating life, but to attempt to tie cost in with

the expected life or MTBRR figures is not possible. First, the MTBRR and other such data are not meaningful because of the failures to replace inferior parts and because of poor documentation. For these reasons, at best MTBRR as applied to the helicopter situation is a subjective rating. On the other hand, the cost of transparencies is difficult to assess since maintenance actions that extend the life of the part should be included. This would be a study in its own right. Finally, inclusion of a cost within a specification is not realistic because it would have to be considered rather low on the priority scale. Certainly, the actual performance requirements would be more important than the cost of the part, especially since the bids are competitive.

GENERAL

To enhance use of this specification, different degrees of importance are assessed to the design requirements shown in Table 3. These ratings are utilized to evaluate conditions that require exceptions or modifications when using the specification. Since the total specification is optimized for the majority of the objectives, actual adjustments and exceptions as necessary will be kept at a minimum.

Evaluation and repeated control of the actual products prepared per this specification are accomplished by detailed qualification and acceptance tests, respectively. Three actual tests and an analysis are specified to qualify transparencies with heating systems. The life cycle test, which combines thermal, pressure, installation and vibration loadings, is proposed as a severe exposure that will defeat inferior product designs. Subsequent flight tests will be the final approval with qualification of appropriate transparencies.

Other tests to substantiate structural quality, fail-safe construction, crashworthiness, and the standard resistances to the elements are included. The actual structural tests to substantiate the integrity of transparencies are addressed to pressure and concentrated loading. An addition of coupons to substantiate the structural quality of production parts will control the final product.

Although tests for abrasion resistance have not been established, this specification defines a requirement that will achieve resistance to surface abrasion. Continuing efforts should be conducted to utilize the recently proposed wiper test, thus substantiating its validity.

To attach some degree of monetary value to the requirements in this specification, a hypothetical analysis is proposed as shown by Table 4. This analysis starts with a simple flat, monolithic transparency. Using this design as a base, subsequent additions of design requirements are shown with the estimated increase in cost. The figures in parentheses represent the actual cost factor for that requirement.

TABLE 4. HYPOTHETICAL COST FACTORS PER DESIGN REQUIREMENTS

Design Requirements		Total Cost Factor
Flat	Monolithic	1
Curved (1.5)		1.5X
	Laminated (1.5)	2.3X
	Bird Proof (1.5)	3.5X
	Heated (1.5)	5.2X
	Static (1.1) Discharge	5.7X
	Ballistic (2.0)	12X
Visual (2.0) Reflection		24X

The information in Table 4 is hypothetical in nature and should only be considered as a guide to demonstrate the relative impact of more sophisticated designs. As an example, this table suggests that a curved transparency with bird proof, heating system and static discharge would cost 5.7 times a monolithic flat panel. Addition of ballistics raises the total cost to 12 times that of a monolithic flat panel.

POTENTIAL CANDIDATE DESIGNS

Based on the problems uncovered during the preliminary study and the design criteria presented to overcome these difficulties, consideration was given to the transparency configurations that would best meet the conditions of the specification. In some cases, it was impossible to optimize the total list of design objectives due to the limitations of available materials. As an example, a low reflection coating does not exist that will withstand the abrasion of a windshield wiper. Also, ballistics protection is inconsistent with weight and optics consideration. Those sections of the specification which the configuration fails to meet either as a result of material unavailability or conflict are listed under Exceptions in Table 5. For the purpose of this discussion, ballistics are only included for the attack helicopter.

TABLE 5. POTENTIAL DESIGN PER SPECIFICATION

Class	Type	Design Configuration	Exceptions
I	I	Antistatic - .09-in. Glass-Heat Element + .09-in. Special Interlayer + .125-in. Polycarbonate - Hard Coat	3.10.2, 3.17, 3.24
	II	Same as Class I, Type I	3.10.2, 3.17, 3.24
	III	Hard Coat-3/16-in. Polycarbonate-Hard Coat (edge reinforcement)	3.10.2
	IV	Same as Class I, Type III	N/A
	V	3/16-in. Acrylic, MIL-P-8184	N/A
	VI	3/16-in. Acrylic, MIL-P-8184	3.9.2
II	I	Antistatic - .09-in. Glass-Heat Element + .09-in. Interlayer (*) + .125-in. Polycarbonate-Hard Coat	3.3.1, 3.3.3, 3.17
	II	.09-in. Glass + .09-in. Interlayer + (*) + .125-in. Polycarbonate-Hard Coat	3.3.1, 3.3.3, 3.17
III	I	Antistatic - .09-in. Glass-Heat Element + .09-in. Special Int. + .125-in. Polycarbonate-Hard Coat	3.17, 3.24
	II	.09-in. Glass + .09-in. Special Interlayer + .125-in. Polycarbonate-Hard Coat	3.17, 3.24
	III	Hard Coat-3/16-in. Polycarbonate-Hard Coat (edge reinforcement)	N/A
	IV	Hard Coat-1/8-in. Polycarbonate-Hard Coat (edge reinforcement)	N/A
	V	1/8-in. Acrylic, MIL-P-8184	N/A
	VI	1/8-in. Acrylic, MIL-P-8184	3.9.2

* Glass Interlayer as required for V50 ballistic limit

In general, composite windshields are recommended for all Type I and II transparencies. The primary reason for this is to combine the durability of glass and the light weight and impact properties of polycarbonate. The advantage of the plastic on the inboard side of the windshield also reduces the hazard of spall in the event of a bird strike or other impact damaging the panel.

In defining the configuration for Type I and Type II windshields, it is recognized that further optimization may be likely. For instance, the importance of weight may dictate the use of glass thinner than the listed .09 in. It is known that a glass thickness of .05 in. has presented problems from impact on commercial type airplanes, so some thickness above this represents the minimum thickness. Conversely, panels utilizing .100-in. outboard glass have shown no problems from impact damage.

For Type III and IV transparencies, it is believed that the performance of monolithic plastic sections is suitable. Scratches are not critical here, and no major problems have been encountered in the past.

Table 5 is a summary of the potential configurations capable of best meeting the developed specification.

CONCLUSIONS

1. Windshields, unlike other transparent structures, have a distinct important function to provide safe, maximum, and undistorted visibility for the pilot in all types of weather and with minimum malfunctions. The most prevalent deterrent affecting windshield function is scratches caused by abrasion from foreign objects, cleaning and primarily wipers. This occurs even though the pilots and maintenance people are sensitive to this and take precautionary and preventive steps to minimize the action. In fact, no wiper use is permitted on helicopters incorporating plastic windshields, even for extreme weather conditions because wiper operation leads to windshield replacement. Such practices have a deleterious effect on the performance of the aircraft.
2. More sophisticated windshield designs with increased functions correspondingly have more problems because of increased failure modes. Failure of laminated windshields with anti-ice/defog systems is a problem experienced with Army all-weather helicopters. As in the case of scratches, use of this system is sometimes restricted. However, neither this problem or restriction exists for the Navy UH-2.
3. Secondary problems experienced with helicopter windshields are reflections and removal/installation difficulties. While these are not failure modes, they do represent serious situations that require solutions. At least one crash caused by windshield reflections has been reported along with drastic actions such as removing objectionable helicopter hardware. Conditions associated with hardened sealants make the replacement of some windshields more burdensome than necessary.
4. Nonwindshield (windows) in helicopters are allowed to remain installed and deteriorate as long as possible with encountered reduced quality tolerated up to the point of total failure. The major portion of windows are replaced because of breaking and cracking caused by: aerodynamic pressure, impact with screwdrivers, accidental stepping through greenhouse windows, combat, etc. Although some windows are replaced because of scratches, this condition is tolerated to a greater degree than for windshields.
5. Data on life obtained from the non-operating agencies did not at all times verify the information gathered from the field. For instance, a glass windshield had a shorter Mean Time Between Repair and Replace (MTBRR) than a plastic windshield did for the failure mode of scratches. This was inconsistent with the field and attributed to the plastic "lived with" conditions and improper use of glass parts or reporting errors.

6. The effect of the operational environment on reliability and maintainability could not be documented with fact, but the main problems identified with the windshields are scratches and anti-icing failure. However, personnel who had maintained or piloted helicopters in different environments cited differences in service performances such as dust and rain experienced in Southeast Asia, causing a greater occurrence of scratches, and that the east coast was associated with more de-icing problems compared with the west coast.
7. Specifications reviewed showed that the major problem of windshield abrasion was covered for only the CH-46 and CH-47 helicopters. However, actual qualification tests of the plastic windshields were not realistic causing a severe problem in the field due to scratching. Conversely, anti-icing was addressed in almost all requirements, but the problem nevertheless occurs in service. A possible explanation is that the tests do not simulate service conditions, or some factors such as water droplet size or vibration are overlooked.

There is a considerable lack of military specifications for the end product windshields and other parts; especially bent parts with increased function although such parts are addressed by industrial specifications. Although some military requirements apply to finished end product, actual qualification tests of finished parts are incomplete.

8. In general, Army preventive maintenance procedures do not adequately detail handling, cleaning and other preventive measures. Conversely, the NAVAIR manual used for the UH-2 shows attention to "preventive" and "repair" type techniques. Repair procedures in the Army manuals are complete and well documented, but subject indexing for windshield parts is lacking.
9. The apparent exceptional performance of the windshield used on the UH-2 all-weather helicopter compared with similar designs of other Navy and Army helicopters is attributed to the balanced glass-glass design and complete preventive maintenance procedures.
10. A complete and comprehensive specification that includes address to all transparent structures on rotary-wing aircraft has been developed. This specification proposes detailed requirements and necessary qualification and acceptance tests to establish the reliability of the design and maintain control of the qualified transparency, respectively. Additional requirements, normally not found in helicopter specification, such as abrasion resistance, reliability, fail safety, crashworthiness, bird proofing, interchangeability, visual reflections and static discharge are detailed and optimized in this specification relative to the priority assessed each objective. Complete coverage of all transparencies is

accomplished by appropriate classification of the aircraft mission and transparency functions in conjunction with an intended applicability per each design requirement. Any modifications considered necessary because of material or process limitations are affected by appropriate adjustments relative to the importance of each requirement.

Because of the various performance conditions possible for ballistic proofing, a special armor and general minimum spall requirement is proposed. Since the requirements are optimized for the general ballistic category only, any use of the special requirement for transparent armor will require, as a minimum, modification of distortion, light transfer and weight.

Since no single abrasion test now exists with repeatability, the developed specification utilizes a combination of tests to ascertain the conformance of transparency materials relative to the requirements. In general, the Taber test defines basic criteria for abrasion, whereas addition of the PPG Abrader Test estimates the performance of the material exposed to ice crystal impingement. As an ultimate requirement, a wiper test, as proposed by AMMRC attempts to simulate actual service. Although this test requires standardization and has yet to be accepted as a standard, it appears to achieve the basic requirements necessary for evaluation of windshield abrasion.

Because of the problems experienced in internal heating systems the anti-ice/defog requirement, as specified, will be evaluated by extensive qualification testing. Tests such as life cycle, thermal shock and cyclic evaluate the basic design with repeated use of heating system at low temperatures. The life cycle test imposes additional loadings of vibration and pressure which achieves the ultimate in effective and worthwhile testing.

Although requirements are proposed for visual reflection, radar reflectivity and heat transfer affecting interior environment, such items are not optimized relative to the rest of the specification because of unavailability of materials. To the present, the only solution of the reflection problems has been effected by costly transparent films that are extremely soft.

In conjunction with the design requirements, the thermal and rather comprehensive structural tests establish the quality of the transparency that will promote reliability. Utilization of production coupons that accompany the processed part will maintain the quality on a continuing basis.

Improvements in maintainability will be achieved by the appropriate designs per the specification, especially for windshield structures. The concurrent issuance of appropriate maintenance documents will also produce a more effective operation.

11. Tests of two current windshield designs showed that monolithic stretched acrylic and two-ply glass laminates cannot sustain a 4-pound bird impact beyond 100 mph. Utilization of polycarbonate, monolithic or laminated with glass, better than doubles the bird resistant capability of current windshield designs.

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GLOSSARY OF COMMON TERMS USED IN AIRCRAFT TRANSPARENCY
MANUFACTURING INDUSTRY

1. Arcing: Indicated by discoloration or charring of conductive film, bubbling and charring of plastic interlayer, and charring of bus bar in spots or streaks.
 - a. Solder Joint Arcing - Characterized as indicated above. Occurs in the general area where the electrical lead wire comes in contact with bus bar.
 - b. Bus Bar Arcing - Characterized as indicated above. Due mainly to deterioration of the interface area between the film and the bus bar.
 - c. Film Arcing - Characterized as indicated above. Caused when film continuity is broken as the result of a chip or break in the glass substrate and results in an arc jumping the area of breakdown.
2. Bubbling: Gaseous inclusions appearing in the interlayer material usually due to overheating of windshields.
3. Burning: Localized severe overheating resulting in charring and discoloring of the interlayer and/or heating film.
4. Chips: Material removed from surfaces or edges of plastic or glass due to external forces imposed on the material itself.
 - a. Peel Chips (Cold Chips)-A shell-type chip pulled from the glass by the interlayer. May damage the adjacent bus bar or conductive film; chips vary in size and shape; best seen by reflected light; causes electrical discontinuity of the damaged bus bar or conductive film and results in localized overheating that may cause arcing, plastic bubbling, and glass breakage; usually accompanied by a larger area of delamination.
 - b. V Edge Chips - Glass damage with considerable depth, resembling the shape of a V; usually caused by impact (tools, foreign objects, etc.).
 - c. Spall Chips - Glass damage, usually very shallow, resembling the pattern of a shell. Usually do not continue to "grow" with further cycling.

5. Control Circuit Failures: Panel will not heat or will overheat, due to failure of sensing element circuit or controller. Abnormal resistance of sensing circuit may result from a broken wire in sensing element or lead wires, failure of solder joint at terminal, or from a short of the sensing element circuit to power circuit or ground. Malfunction sometimes occurs only when panel is stressed by low temperatures.
6. Cracks: Complete separation of glass or plastic structure usually perpendicular to the surface caused by stress imposed on the material.
7. Crazing: Minute cracks on the surface of plastic material usually caused by chemical attack to the material itself.
8. Delamination: A debonding of adhered surfaces.
9. Distortion: A visual defect in glass and plastic caused from a bending of light rays through two nonparallel surfaces.
10. Glass: A transparent amorphous substance consisting ordinarily of a mixture of silicates. Term should not be used to refer to plastic transparencies.
11. Interlayer: The bonding material between two pieces of glass or plastic. Usually vinyl in helicopter windshields.
12. Laminated: A transparent construction of glass/glass, glass/plastic, or plastic/plastic bonded together by an interlayer material.
13. Lite: The plastic or glass portions of a windshield or window, ie, side lite, back lite, door lite, etc.
14. Monolithic: A transparent construction of a single piece of plastic or glass.
15. Pits: A surface defect in plastic or glass roughly circular in shape usually caused by abrasives striking the transparency perpendicular to it and removing a portion of the surface.
16. Plastic: A transparent formable structural material usually as-cast acrylic, stretched acrylic, or polycarbonate. Should not be used as a synonym for glass in transparencies.
17. Rubs: A surface defect in glass or plastic shallow in depth, but having considerable width, generally caused from severe abrasive materials.
18. Scratches: A sharp penetrating surface defect in glass or plastic caused from an abrasive material.

19. Sleaks: Very light scratch in the surface of glass or plastic.
20. Temper: A thermal or chemical process by which glass surfaces are put in compression, thus increasing their strength and resistance to breakage and surface damage.
21. Transparency: Any structural portion of an aircraft allowing clear vision and protection from outside environment.
22. Vinyl: A transparent bonding material commonly used in laminating lites together. Specifically, a plasticized polyvinyl butyral organic substance, sometimes abbreviated as PVB.

APPENDIX I

SPECIFICATIONS

All available documents obtained from the listed helicopter fabricators were reviewed and analyzed. Repeated efforts were made to ensure that the material to be reviewed gave a complete picture. All available documents defining the requirements, specific limits, and associated tests for end products were analyzed and presented in condensed form on Tables 6 through 19. Such tables are mainly concerned with windshield-type transparent structures. The industrial specifications analyzed are normally prepared and in effect between the transparency fabricator and helicopter manufacturer.

MILITARY

A condensed treatment of applicable military documents is found in Tables 20 through 26. In general, all such documents normally define the raw material as supplied to the transparency fabricator. By appropriate additional requirements - MIL-P-25690 (Table 23) and MIL-G-25871 (Table 25) for bent parts - some transfer to end product items is possible. However, the detailed tests for these specifications are only applicable to materials as received for fabrication. Thus, both MIL-P-25690 and MIL-G-25871 define requirements that can be considered as applicable to end products, but the listed acceptance and qualification tests cannot be simply transferred.

FEDERAL STANDARDS

Federal standards for helicopters (FAR-27 and FAR-29) (Table 27) discuss general requirements dealing with pilot view and safety. These documents state that all internal glass shall be safety type and nonsplintering. Also, the pilot's view shall be undistorted and sufficient under all conditions without glare and reflection. Such requirements would tend to suggest the need for rain removal and deice-defog systems. Requirements for fixed-wing aircraft (Table 28) are quite similar. Some additional considerations include structural quality, fail safety and bird proofing.

INDUSTRIAL SPECIFICATIONS (CARGO)

CH-47 and CH-46 Windshields

Tables 6 through 9 show that the specifications for both the CH-47 and CH-46 windshield panels addressed eight or nine requirements. Except for some language in the specifications section, the condensed specifications for windshields in the CH-46 (Navy) and CH-47 (Army) are similar. In fact, the specifications for the deice-defog system in the CH-46 plastic-laminated windshield (Table 8) are not as complete as those for the same design used in the CH-47 (Table 6).

Both Tables 6 and 8 define an abrasion-resistance requirement for the outside ply of the plastic-laminated windshield initially used by the CH-47 and CH-46. A rather extensive test that included 900,000 wiper blade cycles was required. The polyester type outboard ply successfully passed this test with a continuous supply of running water striking the surface. The unrealistic nature of this test was later shown by severe scratching of the outside surface from wiper action in service. According to engineering personnel at Boeing-Vertol, wiper action on partially dry or dirty windshields quickly scratched the surface during qualification tests. Consequently, the industrial specifications for a modified design using glass as the outside ply (Tables 7 and 9) became necessary. Although both current design specifications address abrasion resistance with the use of glass, neither Table 7 or 9 defines any tests.

All four industrial specifications prepared by Boeing-Vertol outlined detailed qualification tests for full-size panels. In general, the more complete qualification tests for the current glass-faced design reflect some experienced problems. The initial tie-down test for the plastic-laminated windshield was replaced by an actual 300-hour flight test with rapid descents. Additional high-humidity and ballistic tests were added, whereas the unrealistic wiper test was eliminated. Because of the lamination and coating features of these parts, the military documents referenced in Tables 20 through 26 are only of value for the basic raw material.

Tables 10 through 14 show all the requirements as defined by Sikorsky's specification control drawings. These drawings with their respective notes define the specifications for the windshield panels in the CH-54, CH-53, and H-3.

CH-54 Windshields

No requirements or tests are defined by the applicable drawings for the CH-54 pilot/copilot (Table 10) or center windshield (Table 14). This supposedly occurred because Sikorsky initially developed this helicopter without Government funding. All requirements for the glass-laminated pilot/copilot windshields and monolithic plastic center windshield are indicated by reference to military specifications. Since the military documents referenced (Tables 23 and 25) have requirements that are applicable to the finished part, these particular designs can be considered specified except for distortion. Also, qualification tests of full-size parts are lacking, and abrasion resistance is not discussed.

CH-53 Windshields

The condensed specifications for the plastic-laminated windshield panels used in the CH-53 (Table 11) show but three requirements. These requirements for optical quality (light transmission), deice-defog, and thermal shock do not have any test definition. Hence, rather than speculate, the associated tests for listed requirements are left undefined. Although

reference to the military specification for stretched acrylic (Table 23) can be associated with end products, the lamination reduces the possibility of such a correspondence. Again, qualification tests of full-size parts are not defined. Requirements such as abrasion resistance and moisture and humidity tests are missing.

H-3 Windshields

Tables 12 and 13 show the same trend (as mentioned for the CH-53) for the two designs used as the pilot/copilot windshield in the H-3. Although five and three requirements are defined respectively for the glass-laminated and plastic-laminated panels, no direct tests exist. The glass-laminated design (Table 12) specification has a significant requirement of reliability beyond that of the plastic-laminated design. However, neither modification nor associated specification shows any consideration for the appropriate qualification tests. Again, references to MIL-G-25871 and MIL-P-25690 (Tables 25 and 23) are of no value beyond material reception because of the heating feature and lamination. Conversely, the reference to MIL-P-25690 for the flat monolithic stretched acrylic center windshield of the H-3 results in a complete list of requirements.

INDUSTRIAL SPECIFICATIONS (UTILITY)

Condensed industrial specifications for the windshields used by utility-type helicopters UH-1 and UH-2 are shown on Tables 15 and 16.

UH-1 Windshields (Table 15)

Bell Helicopter Company directly addresses optical quality and dimensional requirements for the acrylic windshields in the UH-1. No attention to scratch resistance is apparent in their specification. Other requirements such as ballistic and fracture resistance are lacking. The drawings reference military specifications for both stretched and as-cast acrylic, MIL-P-25690 and MIL-P-8184, respectively. It is understood that the stretched acrylic version has never been used for the UH-1 windshield. Since MIL-P-8184 (Table 21) applies to raw materials supplied to the windshield fabricator, a complete specification for the formed windshield is lacking.

UH-2 Windshields

Table 16 shows three additional requirements for windshields in the UH-2 helicopter fabricated for the Navy by Kaman Aircraft. All three requirements are related to the heating feature of the windshield panels. Again, there is no attention to scratch resistance, especially for the plastic-laminated alternate. A structural deflection test is the only qualification condition defined. Reference to the military documents does not lead to a complete specification because of the deice-defog design.

In general, both utility helicopter windshield specifications lack some requirements and qualification tests. Reference to particular military specifications per configuration design fails to define any tests for end products.

INDUSTRIAL SPECIFICATIONS (OBSERVATION AND ATTACK)

Tables 17, 18 and 19 for the acrylic windshields in the OH-6, OH-58, and AH-1G, respectively, show the industrial specification to be quite similar. These specifications only deal with optics and dimensions. No qualification tests are defined by the industrial specification for monolithic acrylic. Again, abrasion resistance is not discussed.

OH-6 Windshields (Table 17)

The plastic windshield in the OH-6 has two different criteria depending on the use of as-cast or stretched acrylic. Texstar Plastics also supplies these parts as spares per the as-cast criteria.

OH-58 and AH-1G Windshields (Tables 18 and 19)

Both industrial specifications for stretched acrylic windshields in the OH-58 and AH-1G reference an industrial procurement specification prepared by Bell Helicopter. This material specification (Table 29) actually combines the requirements of military specifications for acrylic both as-cast and stretched. In some cases, the specified criteria exceed the military documents. Since the referenced military document MIL-P-25690 (Table 23) addresses formed parts of stretched acrylic, the actual specifications can be considered as complete. However, an abrasion resistance requirement is lacking and qualification test of finished part is not defined.

A similar document for polycarbonate prepared by Bell Helicopter is condensed in Table 30. However, none of the drawings or other documents show any use of this material.

WINDSHIELD SUMMARY

Review of all requirements as defined by the industrial specifications is consolidated on Table 31 for all modifications of helicopters of interest. In general, this table shows that the more sophisticated the design - special features such as deice, wipers, etc. - the more requirements are defined. It is quite apparent that abrasion resistance is seldom defined by specifications, industrial or military. Other requirements seldom addressed are reliability and ballistic resistance. Tables 32 and 33, show similar type specifications prevail for laminated heated-glass windshields in nonpressurized fixed-wing aircraft. Comparison between two particular documents shows a variation in the number of requirements per company.

OTHER (NONWINDSHIELD) TRANSPARENCIES

Except for some parts on the CH-47, Bell and Hughes helicopters, specifications are lacking for other formed transparencies of acrylic. Although Boeing-Vertol defines the optics for the formed chin bubble, reference to the military specification MIL-P-8184 does not produce a complete specification. Conversely, a similar arrangement for the side windows does form a complete specification.

Both Bell and Hughes define optics for parts other than the windshields. Reference to MIL-P-25690 for the transparent parts on Bell's OH-58 and AH-1G does appear to accomplish a complete specification, regardless of forming of the material. Conversely, a similar situation for the Hughes OH-6 does not achieve a complete specification with reference to MIL-P-8184 for acrylic as cast because of forming process. Consistent with Bell, Hughes use of stretched acrylic on the OH-6 achieves a complete specification by military reference.

TABLE 6. CONDENSED INDUSTRIAL SPECIFICATION PS-432 FOR
PLASTIC-LAMINATED HEATED WINDSHIELD⁽¹⁾, CH-47

Requirements	Specifications	Tests	
		Qualification	Acceptance (2)
Optical Quality	Grid slope 1:12, subcritical 1:8, 1:4 No objectionable minor optical defects No objectionable patterns of inclusions	No	Yes
Abrasion Resistant	Type I: No scratches caused by 18-in. wipers at .2 to .3 lb/in.	900,000 cycles with running water	No
Fracture Resistant	Bond tensile, 350 psi minimum	No	Yes (3)
Deice & Defog	Dissipation $\pm 15\%$, 115 v Type I: 2,005 w Type II: 283 w	No	Yes
	Bus to Bus $\pm 15\%$ Type I: 6.6 ohms Type II: 46.8 ohms	No	Yes
	Coating flaws by polarized light inspection	No	Yes
	50% Overpower	No	Yes
	Dielectric strength 2,200 v, 60 cps	No	Yes
	Sensing element resistance check	No	Yes
(1) Type I: 114SS601 Pilot/Copilot Panel Type II: 114SS602 Center MIL-P-8184	Bus bar boltage drop .5 v maximum $\pm 10^\circ\text{F}$ Temperature uniformity	No	Yes
		No	Yes
		No	Yes
(2) ER-60-413	Sierracin Process Control		
D8-0005:02.0280	Boeing-Vertol Functional Test Procedure		
(3) Samples representative of part			

TABLE 6 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance (2)
Dimensional	Per drawing and inspection fixture	No	Yes
Reliability	2 to 8 hr/week running water for 6 weeks Deflection per Vertol 114-X-08 35 to 110°F, 2,000 cycles Heat stability per MIL-P-25374	Moisture resistance Structural deflection Temperature cycle No	No No No (3) Yes
Thermal Shock Resistant	-65°F Apply power to design temperature	Thermal shock	Yes
Vibration Resistant	150-hour tie-down operation	Vibration	No
(2) ER-60-413	Sierracin Process Control		
D8-0005:02.0280	Boeing-Vertol Functional Test Procedure		
(3) Samples representative of part			

TABLE 7. CONDENSED INDUSTRIAL SPECIFICATION D8-0660 FOR
GLASS-FACED LAMINATED HEATED WINDSHIELD (1), CH-47

Requirements	Specifications	Qualification (2)	Tests (3)
Optical Quality	Grid slope 1:12, subcritical 1:4 to 1:8 Minor optical defects per MIL-G-25871 Light transmission 70% minimum Haze Alt I: 3% maximum, 4% after high temperature Alt II: 1.2% maximum	No No No No	Yes Yes Yes Yes
Abrasion Resistant	Implied by glass	No	No
Fracture Resistant	Bond shear and tensile, 350 psi Alt I: Tempered glass outboard Alt II: Tempered glass 700 to 1,200 μ Heat distortion per MIL-G-25871	No No No	Yes (4) Yes Yes
Deice & Defog	Dissipation $\pm 15\%$, 115 v Alt I: 1,715 w Alt II: 2,005 w Bus to Bus $\pm 15\%$ Alt I: per drawing Alt II: 9.8 to 13.2 ohms Temperature uniformity $\pm 10^\circ\text{F}$	No No No No	Yes Yes Yes Yes
(1) 114SS604 MIL-G-25871 MIL-P-25690	Pilot/Copilot Panel		
(2) 114-AF-001	Boeing-Vertol Qualification Tests		
(3) QR-70-150 ATP 1691	Sierracin Acceptance and Inspection Procedure for Alt I PPC Industries Acceptance Test Procedure for Alt II		
(4) D8-0005:02.0280 Samples representative of part	Boeing-Vertol Functional Test Procedure		

TABLE 7 - Continued

TABLE 7 - Continued			
Requirements	Specifications	Qualification (2)	Tests (3) Acceptance
Deice & Defog	Hot spots - polarized light inspection	No	Yes
	50% Overpower	No	Yes
	Bus bar voltage drop 1.5 v maximum	No	Yes
	Dielectric strength 2,200 v, 60 cps	No	Yes
	Sensing element resistance check	No	Yes
Dimensional	Per drawing and inspection fixture	No	Yes
Reliability	2 to 8 hr/week running water for 6 weeks	Moisture resistance	No
	Sustain 1,17 psi	Structural deflection	No
	35 to 110°F, 2,000 cycles	Temperature cycle	No
	95% RH at 120°F for 14 days	High humidity	No
	10,000 ft to 1,000 ft, 5 times	Rapid descent	No
Ballistic Properties	Two .30-cal projectiles - maintain visibility	Ballistic	No
	No spall to penetrate helmet		
Thermal Shock	-65°F 2 hr, power to design temperature	Shock resistance	Yes
Vibration Resistant	300-hr flight	Flight	No
(2) 114-AF-001 Boeing-Vertol Qualification Tests			
(3) QR-70-150 Sierracin Acceptance and Inspection Procedure for Alt I			
ATP 1691 PPC Industries Acceptance Test Procedure for Alt II			
D8-0005:02.0280 Boeing-Vertol Functional Test Procedure			

TABLE 8. CONDENSED INDUSTRIAL SPECIFICATION PS-488 FOR (1) PLASTIC-LAMINATED HEATED WINDSHIELD, CH-46			
Requirements	Specifications	Qualification	Tests Acceptance (2)
Optical Quality	Grid slope 1:12, 1-in. border optical free Minor distortion acceptable along phase lines	No	Yes
Abrasion Resistant	No scratches by 18-in. wipers .2 to .3 lb/in.	900,000 cycles running water	No
Fracture Resistant	Bond tensile, 350 psi	No	Yes (3)
Deice & Defog	3.5 \pm 15% w/sq in. at 190 v \pm 10°F temperature uniformity Coating flaws by polarized light inspection Sensing element endurance, 2,000 cycles 3-phase balance	No No No No Yes No	Yes Yes Yes No Yes Yes
Dimensional	Per drawing	No	Yes
Reliability	Running water 4 hr/week for 6 weeks Deflection per 114-X-08 Heat stability per MIL-P-25374	Moisture resistance Structural deflection No	No No (3) Yes
Thermal Shock R.	Full power at -65°F, 25 cycles	Yes	1 cycle
Vibration Resistant	Sustain 150-hr tie-down operation	Vibration	No
(1) A02SS801 Pilot/Copilot Panel MIL-P-8184			
(2) D8-0005:02.0280 Boeing-Vertol Functional Test Procedure			
(3) Samples representative of part			

TABLE 9. CONDENSED INDUSTRIAL SPECIFICATION D210-10337-1 FOR
GLASS-FACED LAMINATED HEATED WINDSHIELD (1), CH-46

Requirements	Specifications	Tests	
		Qualification	Acceptance (2)
Optical Quality	Grid slope 1:12, 1:8 in phase line area Light transmission 70% minimum Haze Alt II: 1.2% maximum	No No No	Yes Yes Yes
Abrasion Resistant	Outside ply high abrasion resistance	No	No
Fracture Resistant	Bond shear and tensile, 350 psi Tempered Glass Alt II: 700 μ minimum	No	Yes (3)
Deice & Defog	3.5 \pm 15% w/sq in. at 190 v \pm 10°F temperature uniformity Coating flaws by polarized light inspection Endurance 2,000 cycles Sensing element resistance 50% Overpower Dielectric strength 2,200 v, 60 cps	No No No Yes No No No No	Yes Yes Yes No Yes Yes Yes Yes
Dimensional	Per drawing and fixture	No	Yes
<p>(1) A02SS808 Pilot/Copilot Panel MIL-G-25871 MIL-P-25690</p> <p>(2) NP-1042-01 PPG Industries Acceptance Test Procedure</p> <p>(3) Samples representative of part</p>			

TABLE 9 - Continued			
Requirements	Specifications	Qualification	Tests Acceptance (2)
Reliability	2 to 8 hr/week running water for 6 weeks Sustain 1.5 psi pressure Heat stability per MIL-P-25374 10,000 ft to 1,000 ft 95% RH at 120°F for 14 days	Moisture resistance Structural deflection No Rapid descent High humidity	No No (3) Yes No No
Ballistic Properties	.30 cal, no spall, maintain visibility	Ballistic test	No
Thermal Shock	-65°F, full power, 25 cycles	Yes	2 cycles
Vibration Resistant	300-hr flight	Flight test	No
(2) NP-1042-01 PPG Industries Acceptance Test Procedure			
(3) Samples representative of part			

TABLE 10. CONDENSED INDUSTRIAL SPECIFICATION 6420-61356 FOR GLASS-LAMINATED WINDSHIELD (1), CH-54			
Requirements	Specifications	Qualification	Tests Acceptance
None			
(1) Pilot/Copilot Panels MIL-G-25871			

TABLE 11. CONDENSED INDUSTRIAL SPECIFICATION 65206-01003, 65206-01009
FOR PLASTIC-LAMINATED HEATED WINDSHIELD (1), CH-53

Requirements	Specifications	Tests	
		Qualification	Acceptance
Optical Quality	Light transmission 74% minimum	Not defined	
Deice & Defog	3.55 w/sq in. at 115 v, 3 phase	-	-
	Bus to bus Type I: 40.6 ohms $\pm 12.5\%$	-	-
	Type II: 62.4 ohms $\pm 12.5\%$	-	-
Thermal Shock R.	Temperature uniformity $\pm 10^{\circ}\text{F}$	-	-
	Operate at -65°F	-	-
	Operate at 110°F	-	-
(1) Type I: 65206-01003 Pilot/Copilot Panel Type II: 65206-01009 Center MIL-P-25690			

TABLE 12. CONDENSED INDUSTRIAL SPECIFICATION S6120-61228
FOR GLASS-LAMINATED HEATED WINDSHIELD (I), H-3

Requirements	Specifications	Tests	
		Qualification	Acceptance
Optical Quality	Light transmission 80% minimum Haze 2%		Not defined
Reliability	Ball drop - no separation	-	-
Deice & Defog	3.0 w/sq in. at 417 v	-	-
	Bus to bus resistance 95.6 ohms $\pm 10\%$	-	-
	Power constants "K" values per drawing	-	-
	Sensing element resistance 286.8 ohms $\pm 25\%$	-	-
	Dielectric	-	-
Dimensional	2,000 v power terminal to metal edge		
	1,000 v sensing terminal to metal edge		
	100 meg. all terminals to metal edge		
Thermal Shock R.	Thickness $\pm .030$	-	-
	Capable of operating at -65°F		
	Withstand 110°F	-	-
	-65°F for 2 hr		
	$+75^{\circ}\text{F}$ for 1 hr, $+161^{\circ}\text{F}$ for 3 hr		
(1) Pilot/Copilot Panels			
MIL-G-25871			
MIL-G-25667			

TABLE 13. CONDENSED INDUSTRIAL SPECIFICATION S6122-87172 FOR
PLASTIC-LAMINATED HEATED WINDSHIELD (1), H-3

Requirements	Specifications	Tests	
		Qualification	Acceptance
Optical Quality	Light transmission 71% minimum		Not defined
Deice & Defog	3.0 w/sq in. at 115/200 v	-	-
	Resistance uniformity $\pm 10\%$ per phase	-	-
	Total resistance tolerance $\pm 12.5\%$	-	-
	Temperature uniformity $\pm 10^{\circ}\text{F}$	-	-
Thermal Shock R.	Capable of operating at -65°F	-	-
	Capable of withstanding 110 $^{\circ}\text{F}$		
(1) Pilot/Copilot Panel MIL-P-8257 MIL-P-25690			

TABLE 14. CONDENSED INDUSTRIAL SPECIFICATION S6122-87171, S6120-61229, 6420-61328 FOR PLASTIC WINDSHIELD (1), H-3, CH-54			
Requirements	Specifications	Qualification	Tests Acceptance
None	(1) S6122-87171 Laminated Pilot/Copilot Panel H-3 MIL-P-77 MIL-P-25690 S6120-61229 Center Panel H-3 MIL-P-25690 MIL-P-8184 6420-61328 Center Panel CH-54 MIL-P-25690 MIL-P-8184		

TABLE 15. CONDENSED INDUSTRIAL SPECIFICATION 204-C30-666
FOR ACRYLIC WINDSHIELD (1), UH-1

Requirements	Specifications	Tests	
		Qualification	Acceptance (2)
Optical Quality	Distortion: Zone A - Grid slope 1:12	No	Yes
	Not impairing vision		
	Zone B - Not impairing vision		
	Major Defects: Zone A - None permitted	No	Yes
	Zone B - Based on location		
	Zone C - Structural only		
	Minor Defects: Zone A - Maximum 4	No	Yes
	Not impairing vision		
	Zone B - Quantity or pattern		
	Not impairing vision		
	Zone C - Structural		
Dimensional	Contour off fixture .8 in. maximum	No	Yes
(1) Pilot/Copilot Panel			
MIL-P-8184			
MIL-P-25690			
(2) Special Acceptance Standard 3017A, Bell Helicopter			

TABLE 16. CONDENSED INDUSTRIAL SPECIFICATION KES-1158
FOR LAMINATED HEATED WINDSHIELD (1), UH-2

Requirements	Specifications	Tests	
		Qualification	Acceptance
Optical Quality	Light transmission 70% minimum	No	Yes
	No abrupt bending of grid from pilot eye	No	Yes
	No objectionable pattern of minor defects	No	Yes
Deice & Defog	Dissipation 2,640 $\pm 10\%$ w at 200 v	No	Yes
	Bus to bus 15.3 ohms $\pm 10\%$	No	Yes
	No coating flaws or hot spots	No	Yes
	50% Overpower	No	Yes
	Bus bar voltage drop .5 v maximum	No	Yes
	$\pm 10^\circ\text{F}$ temperature uniformity	No	Yes
	Dielectric strength 1,400 v, 60 cps	No	Yes
Dimensional	Lead strength Alt I: 15 lb minimum	No	Yes
	Per drawing	No	Yes
Reliability	0 to .5 psi, 500 cycles at room temperature	Structural deflection	No
	.75 psi at 105 and -65°F		
Thermal Shock R.	-65°F 2 hr, to room temperature air at 160°F	Yes	Yes
	-20°F , apply 110 v and increase to 200 v	Yes	No
	-65°F , apply 110 v and increase to 200 v	Yes	No
	-20°F , apply 200 v	Yes	No
	-65°F , apply 200 v	Yes	No
(1) Alt I: K633035-85/86 Glass Laminated Pilot/Copilot MIL-G-25667			
Alt II: K633035-131/132 Plastic Laminated Pilot/Copilot MIL-P-8184			

TABLE 17. CONDENSED INDUSTRIAL SPECIFICATION 369A2404
FOR ACRYLIC WINDSHIELD (1), OH-6

Requirements	Specifications			Tests	
	Distortion:	Zone A - Grid Slope	Alt I: 1:4 Alt II: 1:6	Qualification	Acceptance (2)
Optical Quality		Zone B - Alt I: No objectionable patterns. Alt II: Grid slope 1:4		No	Yes
	Zone C - Structural				
Major Defects:	Zone A&B - Alt I: None permitted Zone A,B,C, - Alt II: None permitted			No	Yes
Minor Defects:	Zone A - Alt I: one/4 in. dia circle Alt II: 3/32 in. dia, 2 maximum Zone B - Alt I: No objectionable patterns Alt II: one/4 in. dia circle Zone C - Alt II: No objectionable patterns.			No	Yes
Dimensional	Per Drawing			No	Yes
(1) Pilot/Copilot Panel (Hughes)	369A2404--601/602 Center Left/Right-hand 369A2404--603/604 Lower Left/Right-hand				
Alt I: MIL-P-5425 Alt II: MIL-P-25690					
Spares - Pilot/Copilot Panel (Texstar)*	5001424/5001425 Center Left/Right-hand 5001423/5001422 Lower Left/Right-hand				
(2) Hughes Process Specifications					
Alt I: HP30-69 Alt II: HP30-68					
*Spares supplied by Texstar Plastics per Alt I requirements					

TABLE 18. CONDENSED INDUSTRIAL SPECIFICATION 206-031-115 FOR ACRYLIC WINDSHIELD (1), OH-58			
Requirements	Specifications	Qualification	Tests Acceptance (2)
Optical Quality	Distortion: Zone A - Grid slope 1:10 Zone B - Grid slope 1:6 Zone C - Structural	No	Yes
	Major Defects: Zone A - None permitted Zone B - None permitted Zone C - Structural	No	Yes
	Minor Defects: Zone A - 2 per sq ft Zone B - 3 per sq ft Zone C - Structural	No	Yes
Dimensional	Contour off fixture .8 in. maximum	No	Yes
(1) Pilot/Copilot Panel - 206-031-115 Left-hand, 206-032-115 Right-hand 299-947-090 Type III (2) Special Acceptance Standard 3023, Bell Helicopter			

TABLE 19. CONDENSED INDUSTRIAL SPECIFICATION 209-030-509
FOR ACRYLIC WINDSHIELD (1), AH-1G

Requirements	Specifications	Tests	
		Qualification	Acceptance (2)
Optical Quality	Distortion:		
	Zone A - Grid slope 1:10	No	Yes
	Zone B - Grid slope 1:6		
	Zone C - Structural		
Major Defects:	Zone A - None permitted	No	Yes
	Zone B - None permitted		
	Zone C - Structural		
Minor Defects:	Zone A - 1 per sq ft	No	Yes
	Zone B - 2 per sq ft	No	
	Zone C - Structural		
Dimensional	Thickness (after forming)	No	Yes
	Center panel .187-in. thick $\pm .040$		
	Others: .135 to .185 in.		
(1) Center Panel 299-947-090 Type III			
Other Panels 299-947-090 Type III			
209-030-507/516 Forward Left/Right			
209-030-515/508 Rear Left/Right			
(2) Special Acceptance Standard 3022, Bell Helicopter			

TABLE 20. CONDENSED MILITARY SPECIFICATION MIL-P-5425
ACRYLIC, HEAT RESISTANT

Requirements	Specifications	Tests	
		Qualification	Acceptance
Minor Optical Defects	Imbedded particles, bubbles, scratches Maximum number 1/4-sq ft area	No	Yes
Angular Deviation	To .220-in. thick: 7 minimum, 1-in. border .220 in. to .500 in.: 7 minimum, 3-in. border	No No	Yes Yes
Light Transmission	Original 90 to 91% After weathering 1% less	Yes Yes	Yes No
Haze	Original 3% maximum After weathering 4% maximum	Yes Yes	Yes No
Index of Refraction	1.49 \pm 0.01	Yes	No
UV Transmittance	Less than 5%	Yes	No
Thermal Stability	No blistering, 356°F, 2 hr	No	Yes
Tensile Strength	8,000 psi minimum	Yes	No
Elongation	2% minimum before fracture	Yes	No
Warpage	.080 to .100-in. thick: .020 in. maximum Greater than .100-in. thick: .015 in. maximum	Yes Yes	No No

TABLE 20 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
Rate of Burning	Maximum 1.5 to 2.5 in. per minute	Yes	No
Specific Gravity	1.19 \pm .01	Yes	No
Water Absorption	.2% to 1.0%	Yes	No
Thermal Expansion	Maximum .000055 per $^{\circ}$ F	Yes	No
Internal Strain	Maximum 1% dimensional change after heating	Yes	No
Deformation Temperature	Up to 1/2-in. thick: 185 to 239 $^{\circ}$ F flexural	No	Yes
Dimensions	Linear \pm .06 in.	No	Yes
	Thickness less than .125-in. thick: \pm .012 in.	No	Yes

TABLE 21. CONDENSED MILITARY SPECIFICATION MIL-P-8184
MODIFIED ACRYLIC

Requirements	Specifications	Tests	
		Qualification	Acceptance
Minor Optical Defects	Imbedded particles, bubbles or scratches Maximum number 1/4-sq ft area	No	Yes
Angular Deviation	.060 to .220-in thick: maximum 7 min, 1-in. border .221 to .500-in thick: maximum 7 min, 3-in. border	Yes Yes	Yes Yes
Light Transmission	Original 90 to 91% After weathering 1% less	Yes Yes	No No
Haze	3% maximum After weathering 4% maximum	Yes Yes	No No
Thermal Stability	356°F for 2 hr, no blistering or crazing	Yes	No
Crazing	248°F for 2 hr, apply solvents no crazing, cracking or degradation	Yes	No
Tensile Strength	9,000 psi minimum	Yes	No
Tensile Elongation	2% minimum	Yes	No
Thermal Expansion	.00010/°C (-30° to +50°C)	Yes	No
Internal Strain	1% maximum dimensional change	Yes	Yes

TABLE 21 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
UV Transmittance	5% maximum (290 to 330 μ)	Yes	No
Index of Refraction	1.48 to 1.50	Yes	No
Specific Gravity	1.18 to 1.20	Yes	No
Thermal Deflection	Varies with thickness	Yes	Yes
Water Absorption	Varies with thickness	Yes	No
Flammability	Varies with thickness	Yes	No
Warpage	Varies with thickness	Yes	No
Thickness Tol.	Varies with thickness	No	Yes

TABLE 22. CONDENSED MILITARY SPECIFICATION MIL-P-8257
THERMOSETTING PLASTIC

Requirements		Specifications	Qualification	Tests	Acceptance
Material	Transparent				
Minor Optical Defects	Scratches & blemishes, imperfections causing greater than 5 min deviation maximum number 1/4-sq ft area		No		Yes
Angular Deviation	Less than .220-in. thick: 5 min, 1-in. border, .220 to .500-in. thick: 5 min, 3-in. border		No		Yes
Light Transmission	Original 90% to 89% After accelerated weathering, 1% less		No Yes		Yes No
Haze	Original 4% After accelerated weathering, 4.5%		No Yes		Yes No
Index of Refraction	1.55 ± .03		Yes		No
Elongation	Greater than 2.5% before fracture		Yes		Yes
Tensile Strength	Polyester base greater than 8,500 psi, allyl base greater than 5,500 psi		Yes		Yes
Impact Strength	Izod - greater than 1.25 lb/in. unnotched, greater than .20 lb/in. notched		Yes		No

TABLE 22 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
Flexural Strength	Polyester base greater than 16,000 psi, allyl base greater than 8,000 psi	Yes	No
Deformation Temp.	Flexural 176°F minimum	No	Yes
Internal Stress	Less than 1 fringe/in. thickness, any 6 in.	Yes	Yes
Crazing	No crazing from 6 months Fla. exposure	Yes	No
Dimensional Change	Maximum 1% change after heating	Yes	No
Thermal Expansion	.000061 per °F	Yes	No
Rate of Burning	Less than 1.25 to 2.1 in./min	Yes	No
Water Absorption	Maximum .09% to .7%	Yes	No
Warpage	Maximum .01 to .09	Yes	No
Specific Gravity	Maximum 1.31	Yes	No
Dimensional Tol.	Linear ±.06 up to 40-in.	Yes	Yes
	Thickness .060-in. ±.003, to .375-in. ±.018	Yes	Yes

TABLE 23. CONDENSED MILITARY SPECIFICATION MIL-P-25690
STRETCHED ACRYLIC

Requirements	Specifications	Tests	
		Qualification	Acceptance
Material	Modified acrylic sheets, MIL-P-8184 Multiaxially or biaxially stretched		
Minor Optical Defects	Imbedded particles, bubbles or scratches shall not exceed 1 per sq ft.	Yes	Yes
Angular Deviation	7 min maximum, formed parts per drawing	Yes	Yes
Optical Distortion	Formed parts, 14 min in 6 in. maximum	Yes	Yes
Light Transmission	Original .06 to .22-in. thick, 91% minimum	Yes	Yes
	After weathering, 89% minimum	Yes	No
Haze	Original 3% maximum	Yes	Yes
	After weathering 4% maximum	Yes	No
Crack Propagation	0°F: "K" minimum average 1,250, minimum 1,150	Yes	No
	Flat: "K" minimum average 2,700, minimum 2,300	Yes	Yes
	Formed: "K" minimum average 2,600, minimum 2,200	Yes	Yes
	After natural weathering -		
	Flat: "K" minimum average 2,300	Yes	No
	Formed: "K" minimum average 2,100	Yes	No
Thermal Relaxation	At 230°F 10% maximum, at 293°F 40% minimum	Yes	Yes

TABLE 23 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
Craze Resistance	No craze or crack after test	Yes	No
Tensile Strength	Av. 9,000 psi minimum	Yes	No
Shear Strength	Av. 3,000 psi minimum	Yes	No
Dimensional Stability	Natural weathering 0.2% maximum change	Yes	No
Dimensional Tol.	Less than 40-in. length: ± 0.062 in.	Yes	Yes
	Greater than 40-in. length: ± 0.125 in.	Yes	Yes
	Flat: Less than .250-in. thick: ± 0.020 in.	Yes	Yes
	Greater than .250-in. thick: $\pm 10\%$	Yes	Yes
	Formed: Per drawing or specification	Yes	Yes

TABLE 24. CONDENSED MILITARY SPECIFICATION MIL-P-25374A
MODIFIED ACRYLIC LAMINATED

Requirements	Specifications	Qualification	Tests (1)	Acceptance
Material Acrylic Sheet Interlayer	MIL-P-8184 PVB 37.5 \pm 2 PPH Plasticizer	Yes		Yes
Minor Optical Defects	Imbedded particles, blemish, bubble, scratch maximum number 1/2-sq ft area	Yes		Yes
Angular Deviation	10 to 20 min, varies with thickness	Yes		Yes
Optical Distortion	12 inches minimum	Yes		Yes
Light Transmission	Original 87% to 90% Accelerated weathering 86% to 89% Natural weathering 85% to 88%	Yes Yes Yes		Yes No No
Haze	4% maximum	Yes		Yes
Resistance to Weathering	No crazing, cracking, or interlayer instability that reduces visibility	Yes		Yes

(1) By USAF

TABLE 24 - Continued

TABLE 24 - Continued			
Requirements	Specifications	Qualification (1)	Tests Acceptance
Shear Strength	Minimum average 500 psi, minimum 450 psi	Yes	Yes
Interlayer Peel	Rate: Minimum 2.5 min/in.	Yes	Yes
	Minimum 1 min/in. after Fla. weathering	Yes	Yes
Impact Strength	Minimum 7 ft-lb/in.	Yes	Yes
Fracture Resistance	Falling ball, 2 pieces or less	Yes	Yes
	No delamination outside 1-in. diameter		
Heat Distortion	0°F, 2-lb falling ball from 10 ft	Yes	Yes
	2 pieces or less, no exposed interlayer, no delamination greater than .25 in.		
Heat Distortion	Minimum 185°F	Yes	Yes
Temperature Stability	After 275°F, no bubbling, discoloration	Yes	Yes
Thermal Shock	-40°F, +212°F, no delamination, cracking, crazing	Yes	Yes
(1) By USAF			

TABLE 25. CONDENSED MILITARY SPECIFICATION MIL-G-25871A
GLASS, LAMINATED, AIRCRAFT GLAZING(1)

TABLE 25. CONDENSED MILITARY SPECIFICATION MIL-G-25871A GLASS, LAMINATED, AIRCRAFT GLAZING(1)					
Requirements		Specifications	Qualification	Tests	Acceptance
Material Glass Interlayer	MIL-G-25667 P V B 21 PPH Plasticizer				
	Design & Construction	Per applicable drawings			
Temper		MIL-G-25667 or drawings			
Dimensional Tol.		Thickness $\pm .03$ -in.			
		Linear, annealed assembly to .250: $\pm .03$ over .250: $\pm .06$	No	Yes	Yes
		tempered assembly $\pm .06$	No	Yes	Yes
		Mismatch, tempered assembly $\pm .06$	No	Yes	Yes
Thermal Shock		Flatness (Class A) 500 ft radius	No	Yes	Yes
		Curvature (Class B) .125 in. off fixture	No	Yes	Yes
		-65°F 2 hr, 75°F 1 hr, 161°F circulating air 2 hr - no cracking, clouding or delamination	No		Yes
	(1) Except Types III and IV				

TABLE 25 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
Nonscatterability	Ball drop to fracture glass plies no separation of glass or interlayer	No	Yes
Light Transmission	Original and after exposure, varies with thickness	No	Yes
Haze	Maximum 2%	No	Yes
Optics, Critical Areas	No minor defects forming objectionable pattern, or dimensions exceeding .03 to .09 in. dia.	No	Yes
Optical Deviation	Class A, 31.5 seconds of arc Others per drawing	No	Yes
Optical Distortion	Per drawing	No	Yes

TABLE 26. CONDENSED MILITARY SPECIFICATION MIL-P-83310
POLYCARBONATE

Requirements	Specifications	Tests	
		Qualification	Acceptance
Material	Transparent		
Minor Optical Defects	Imbedded particles, bubbles, scratches, or imperfections causing 5 min deviation maximum maximum number 1/4-sq ft area, maximum 2/sq ft	Yes	No
Angular Deviation	To .220-in. thick: 7 min, 1-in. border .220 to .500-in. thick: 7 min, 3-in. border	Yes Yes	Yes Yes
Light Transmission	Original .060-in.: 88% minimum, .375-in.: 82% minimum After accelerated weathering 2% less	Yes Yes	Yes No
Haze	Original 3% maximum After accelerated weathering, 4% maximum	Yes Yes	Yes No
Index of Refraction	1.59 \pm .01	Yes	No
Crazing	No crazing from ethylene glycol, no crazing from accelerated weathering	Yes	No
Ultraviolet	Stabilized	Yes	No
Tensile Strength	8,800 psi minimum (ultimate)	Yes	No

TABLE 26 - Continued			
Requirements	Specifications	Qualification	Tests Acceptance
Elongation	At rupture 80% minimum	Yes	No
Deflection Temp.	260°F minimum, under load	Yes	Yes
Thermal Expansion	.000055 per °F (-22° to +122°F)	Yes	No
Impact Strength	Izod - .060 to .187-in.: 12 ft-lb/in. of notch .250 & .375-in.: 2.5 ft-lb/in. of notch	Yes Yes	No No
Flammability	25% minimum oxygen index	Yes	No
Internal Strain	Maximum 1% dimensional change after heating	Yes	No
Specific Gravity	1.20 ±.01	Yes	No
Dimensions	Linear ±.06 in. Thickness .060-in. ±.006 to .375-in. ±.03	Yes Yes	No No

TABLE 27. CONDENSED FEDERAL STANDARDS FAR-27, FAR-29
WINDSHIELD ROTORCRAFT (1)

Requirements	Specifications	Tests (2)	
		Qualification	Acceptance
Optical Quality	Pilot's view free and undistorted for safe day and night operation - no glare or reflections	Flight test	No
Environment	Protection from elements for sufficient view along flight path		
Deice & Defog	Type II: If certified, safe flight operation		
Safety	Internal glass safety type, nonsplintering		
(1) Type I: FAR-27 Normal Rotorcraft			
Type II: FAR-29 Transport Rotorcraft			
(2) Requirements without comments indicate tests not defined by documents			

TABLE 28. CONDENSED FEDERAL STANDARDS FAR-23, FAR-25
WINDSHIELD FIXED-WING AIRCRAFT⁽¹⁾

Requirements	Specifications	Tests ⁽²⁾	
		Qualification	Acceptance
Optical Quality	Pilot's view free and undistorted for safe day and night operation, no fatigue or glare Type I: 70% minimum light transmission	Flight test	No
Environment	Compartment protected from rain and snow, sufficient view along flight path for safe operation		
Deice & Defog	Type II: If certified, safe flight operation		
Safety	Internal glass safety type, nonsplintering minimum flying fragments		
Structural Quality	Windows sustain combined effects of pressure, temperature and aerodynamic loads		
Fail Safe	Type II, Type I (operation at 25,000 ft): Sustain combined loading after failure of a structural member		
Bird Proof	Type II: Sustain 4-lb bird strike without penetration		
(1) Type I: FAR-23 Normal Utility and Acrobatic Type II: FAR-25 Transport			
(2) Requirements without comments indicate tests not defined by documents.			

TABLE 29. CONDENSED INDUSTRIAL SPECIFICATION
299-947-090 - MATERIAL PROCUREMENT

Requirements		Specifications	Qualification	Tests	Acceptance
Material					
Type I:	Acrylic, Heat Resistant, MIL-P-5425 Finish "A"				
Type II:	Acrylic, Heat & Craze Resistant, MIL-P-8184 Finish "A"				
Type III:	Acrylic, Heat, Craze & Crack Resistant, MIL-P-25690 Flat				
Type IV:	General Grade				
Minor Optical Defects	Imbedded particles, bubbles or scratches not to exceed 1 per sq ft-shall cause 5 min deviation maximum		No		Yes
Angular Deviation	5 min maximum, 3-in. border		No		Yes
Optical Distortion	14 min maximum, in 12 in.		No		Yes
Light Transmission	Maximum UV 5%		Yes		No
Haze	2% maximum		No		Yes
Tensile Strength	Type I, IV: 8,500*		Yes		No
	Type II, III: 9,500		Yes		No
* Additional requirements over MIL Documents where applicable					

TABLE 29 - Continued

Requirements	Specifications	Tests	
		Qualification	Acceptance
Tensile Elongation	2.5% minimum except Type III*	Yes	No
Internal Strain	.75% maximum: Less than 10% at 230°F Greater than 40% at 293°F	Yes	No
Dimensional Tol.	Lineal $\pm .06$ in. Thickness, varies with thickness	No No	Yes Yes
Following Apply to Type IV Only			
Formability	Shrink 2% lineal and 4% thickness	Yes	No
Water Absorption	.2% to 1.0%, varies with thickness	Yes	No
Burning Rate	1.5 to 2.5 in./minimum, varies with thickness	Yes	No
UV Transmittance	5% maximum, 250-in. thick	Yes	No
Specific Gravity	1.19 \pm 0.01	Yes	No
*Additional requirements over MIL Documents where applicable			

TABLE 30. CONDENSED INDUSTRIAL SPECIFICATION 299-947-044 -
POLYCARBONATE PROCUREMENT

Requirements	Specifications	Tests	
		Qualification(1)	Acceptance
Warpage	Maximum deviation from flat 1 in. across 48 in., .5 in. across 24 in.	No	Yes
Specific Gravity	1.19 to 1.22	Yes	No
Deflection Temp.	Greater than .040-in. thick: 262°F at 264 psi stress	Yes	No
Distortion Temp.	.010 to .060-in. thick: 284°F	Yes	No
Shrinkage, Linear	.5% maximum after 24 hours at 140°C	Yes	No
Tensile Strength	8,000 psi minimum (yield)	Yes	No
Flexural Strength	11,000 psi minimum (yield)	Yes	No
Tensile Elongation	60% minimum (ultimate)	Yes	No
Impact Strength	Izod -.125-in.: 12 ft-lb/in. of notch, .250-in.: 1.8 ft-lb/in. of notch	Yes	No
Brittleness	-55°C	Yes	No
Water Absorption	24 hr .15% maximum	Yes	No

(1) Includes all acceptance tests of L-P-393

TABLE 30 - Continued

Requirements	Specifications	Tests Qualification (1)	Acceptance
Dielectric Strength	400 v/mil maximum, 60 cps	Yes	No
Flammability	Self-extinguishing	Yes	No
Dimensions	Thickness - varies with thickness, linear - varies with thickness	No	Yes
(1) Includes all acceptance tests of L-P-393			

TABLE 31. CONSOLIDATED REQUIREMENTS FOR HELICOPTER WINDSHIELDS

	Laminations										Monolithic Acrylic					
	Plastic-Plastic					Glass Faced					Glass-Glass			Stretched		
Requirements	47*	46	53	3	2	47	46	54	3	2	1G	3	6	54	1	6
Optical Quality	++	+	+	+	+	+	+	-	+	+	+	-	+	-	+	+
Abrasion R.	+	+	0	0	0	+	+	0	0	0	0	0	0	0	0	0
Fracture R.	+	+	0	0	0	+	+	-	+	0	-	-	-	-	-	-
Deice-Defog	+	+	+	+	+	+	+	0	+	+	0	0	0	0	0	0
Dimensional	+	+	-	-	+	+	+	-	+	+	+	-	+	-	+	+
Reliability	+	+	0	0	+	+	+	-	0	+	0	0	0	0	0	0
Ballistic R.	0	0	0	0	0	+	+	0	0	0	0	0	0	0	0	0
Thermal Shock	+	+	+	+	+	+	+	-	+	+	0	0	0	0	0	0
Vibration R.	+	+	0	0	0	+	+	0	0	0	0	0	0	0	0	0

*Numbers refer to particular helicopter models.
**Code: + indicates direct definition by industrial specification.
- indicates requirements as applicable per military specifications.
0 indicates no requirement for end product.

TABLE 32. CONDENSED INDUSTRIAL SPECIFICATION 1301
WINDSHIELD - PIPER AIRCRAFT

Requirements	Specifications	Tests (1)	
		Qualification	Acceptance
Fracture Resistance	Semitempered glass	No	Yes
Deice & Defog	Power input per drawings at 28 v DC		
	Resistance per drawing	No	Yes
	50% Overpower	No	Yes
	Dielectric strength 2,500 v, 60 cps	No	Yes
Thermal Shock	-65°F 2 hr, 150% power to design temperature	No	Yes
(1) Requirements without comments indicate tests not defined by documents.			

TABLE 33. CONDENSED INDUSTRIAL SPECIFICATION BS-4296
WINDSHIELD (1) - BEECH AIRCRAFT

Requirements	Specifications	Tests (2)	
		Qualification	Acceptance
Optical Quality	Distortion per MIL-G-25871 80% minimum light transmission		
Fracture Resistance	Class 1,300 μ minimum average		
Deice & Defog	3 w/sq in. ² at 28 v DC	No	Yes
	Bus to bus resistance 1.2 ohms	No	Yes
	50% Overpower	No	Yes
	Terminal blocks withstand 50 in.-lb torque	No	Yes
	Sensing elements 10 v DC for 1 min	No	Yes
	Static removal by outside coating		
	2,500 v, 60 cps for 1 min dielectric test	No	Yes
Dimensional	.12 in. bend departure		
Reliability	3,500 hr service life		
Thermal Shock	-65°F 2 hr, apply 150% power to design temperature	No	Yes
(1) Beech P/N 50-384047			
(2) Requirements without comments indicate tests not defined by documents.			

APPENDIX II
OPERATIONAL ENVIRONMENT

The following natural environmental elements affect helicopter transparencies to some degree, depending on the type of material used.

NATURAL ELEMENTS

Temperature	Rain
Humidity	Ice particle impingement
Dust/sand	Hail
Salt water	Ultraviolet radiation

OPERATIONAL ELEMENTS (MAN-MADE)

Ballistic projectiles and fragments
Chemical attack by solvents, cleaning compounds, and fuel
Windshield-wiper operation
Airframe rack and twisting

EFFECTS REPORTED

Following are the most serious and frequent effects reported and observed in the field in order of importance and/or occurrence:

1. Scratches
2. Cracking/crazing
3. Electrical failure (on electrothermal deice windshield)
4. Delamination

MATERIAL TYPES

Analysis of the causes of these effects must be directed toward the type of transparent materials being used. Basically, there are two types now in use.

Monolithic

1. Acrylic as-cast
2. Acrylic stretched
3. Polycarbonate (coated and uncoated)

Laminates

1. Glass/interlayer/glass
2. Glass/interlayer/stretched acrylic
3. Polyester/interlayer/stretched acrylic

CAUSE AND EFFECT

Over the years, data have been generated in various laboratory tests to determine the relative merit of different transparent materials when exposed to natural and man-made elements. Correlation of these data with field results is not precise. However, the results of these tests can be stated, and a material choice made. However, such items as maintenance and replacement costs must also be evaluated based on intended mission profile and use.

The following discussion relates cause and effect to natural and man-made elements with regard to outer surface exposure, whether monolithic or laminated.

Scratches

Scratches are mainly caused by improper handling and windshield-wiper abrasion.

Resistance to scratching is a function of the transparent material hardness. Lab test and field observation show glass to be the best and acrylic/polycarbonate the least resistance to scratching and abrasion.

Cracking/Crazing

Cracking/crazing caused by:

1. Particle or object impingement
2. Chemical attack
3. UV attack

Resistance to cracking is dependent on particle impingement, energy level and concentration, modulus of rupture, thickness, temperature, brittleness, notch sensitivity, and resistance to chemical attack.

Acrylics

Unstretched acrylic plastics are moderately notch sensitive and particularly susceptible to crazing. Polyesters are highly resistant to crazing but are extremely notch sensitive and, therefore, mostly used in laminated form. Stretched acrylic plastics have more resistance to notch effects than unstretched, monolithic or laminated, as well as a greater resistance to crazing. Stretched acrylics exhibit a sensitivity to the bonding of other materials which is more pronounced than its notch sensitivity.³ Unstretched acrylic is highly sensitive to stress concentrations and presents little resistance to crack propagation.

Chemical stress crazing tests conducted on as-cast acrylic, stretched acrylic, and extruded polycarbonate confirm in general that stretched acrylic is the most resistant and polycarbonate the least resistant.

Polycarbonate

Polycarbonate's most serious weakness is its chemical resistance. Although polycarbonate has good resistance at room temperature to water, dilute inorganic and organic acids, solutions of neutral and acid salts, vegetable oils, aliphatic hydrocarbons, ethers, and alcohols, it is readily dissolved by certain halogenated solvents such as methylene chloride, 1, 2 dechloroethane, and chloroform. Plasticization and crystallization can result from contact with partial solvents such as low molecular weight aldehydes and ether, ketones, ester, aromatic hydrocarbons, and perchlorinated hydrocarbons. Chemical attack ranging from partial to complete destruction of the part occurs in contact with alkali, alkaline salts, amines and ozone.⁴

Combination of certain environments and tensile stresses can cause stress cracking or crazing in polycarbonate. A stress crack is localized failure and a stress craze an area of localized yield. Crazing can be induced at high stress levels by low molecular weight hydrocarbons and alcohol. Carbon tetrachloride, acetone, and zylene may cause cracking at low stress levels and should be avoided.⁴

Tests of polycarbonate confirms that crazing only takes place when polycarbonate is stressed in tension. Crazing of polycarbonate was retarded when tested in compression.

Abrasion Resistance (Taber Test)

Test results of loss of light transmission according to ASTM Method 1092.1 show stretched acrylic loses 40.4% compared to 51.0% for polycarbonate.⁵

Hard coatings

During the last several years, hard coatings have been developed to protect plastics from surface damage caused by chemical and abrasion attack.

Dupont, Owens-Illinois, and others have hard coatings in limited use. However, experience encountered by WPAFB Material Lab and Cessna with polycarbonate on the T-37 aircraft indicates adhesion and possible ultraviolet radiation difficulties. As of this date, the failure mechanisms involved have not been defined or explained.

LAMINATES

Glass windshields are used where resistance to abrasives is desired. It is well known and documented that glass is superior to plastics when subjected to abrasion, weathering, and chemical attack. All of the known

aircraft glass transparencies are laminated except for some special camera windows. Laminated glass windows in use can and usually do incorporate an electro conductive transparent heating film for defog and anti-ice protection.

A comparison and merit rating of relative durability of transparent materials is shown in Table 34. More specific properties appear in Table 35.

TABLE 34. RELATIVE DURABILITY OF TRANSPARENT MATERIALS AGAINST SELECTED ITEMS					
Elements	Stretched Acrylic MIL-P-25690A	Cast Acrylic MIL-P-8184	Polycar- bonate 9030	Polyester MIL-P-8257	Glass MIL-G-25667
Aerial Density	4	4	3	2	1
Temperature Change	4	2	3	1	5
Moisture Absorption	2	2	4	2	5
Ice Particle	2	2	1	3	5
Ultraviolet Radiation	2	2	1	4	5
Dust and Sand	3	2	1	4	5
Chemical (General)	3	2	1	4	5
Crazing	3	2	1	4	5
Heat Distortion	3	2	4	1	5
Hardness	3	3	1	2	5
Resistance to Crack Propagation	<u>4</u>	<u>3</u>	<u>5</u>	<u>2</u>	<u>1</u>
TOTALS	33	26	25	29	47
1 = Least Durable 5 = Most Durable					

TABLE 35. TYPICAL PROPERTIES OF GLAZING MATERIALS						
Property	Units	Thermally Tempered Glass	Chemically Tempered Glass	Poly- Carbonate	As Cast Acrylic MIL-P-8184	Stretched Acrylic MIL-P-25690
Specific Gravity	NA	2.5	2.40	1.20	1.19	1.19
Luminous Transmittance	%	88	91.6	84	92	91
Haze	%	N/A	N/A	2	1	-
Coefficient of Thermal Expansion	10 ⁻⁶ in./ in. OF	4.8	5.2	38.0	38.0	35.0
Thermal Conductivity	BTU/hr/ sq-ft/OF in.	6.5	6.5	1.3	1.2	1.2
Specific Heat	BTU/lb/OF	0.205	0.205	0.30	0.35	0.35
Refractive Index	NA	1.518	1.516	1.586	1.50	1.50
Poisson's Ratio	NA	0.22	0.22	0.37	0.35	0.35
Heat Distortion Temperature	OF	1100	1100	300	212	212
Tensile Strength	psi	25,000	35,000	9,500	11,000	11,000
Elastic Modulus	10 ⁶ psi	10	10.2	0.34	0.45	0.45
Elongation Maximum	%	0.25	0.35	110	5.1	-
Rockwell Hardness	Moh's	(6)	(6)	M-70	N-93	M-96
Water Absorption	%	0	0	.35	1.9	-

APPENDIX III

PERFORMANCE

At each service facility, all available information, both commentary and documentary, was gathered on the performance of the transparent structures in helicopters. Such information was also obtained from the helicopter manufacturers as available. In order to group the parts in this study, consistent with the specifications section, the classification shown in Table 36 was utilized. This classification, on the basis of helicopter and transparency function, groups the helicopters under consideration for comparative purposes.

TABLE 36. HELICOPTER TRANSPARENCY CLASSIFICATION			
Helicopter Class	Windshield	Cockpit Windows	Cabin Windows
Cargo	CH-47	CH-47	CH-47
	CH-54	CH-54	
	CH-46*	CH-53*	
	CH-53*	HH-3*	
	HH-3*		
Utility	UH-1	UH-1	UH-1
	UH-2*	UH-2*	
Attack	AH-1G	AH-1G	
	AH-56	AH-56	
Observation	OH-6	OH-6	OH-6
	OH-58	OH-58	OH-58
* Non-Army Helicopters			

FAILURE MODES

Failure modes causing replacement and repair of windshields and other transparencies were determined from an analysis of all available data. Tables 38 to 55 tabulate the results with maintenance actions and maintenance times when available. Whenever possible the specific maintenance actions are separated for particular failure modes.

REPLACEMENTS

Failure information was tabulated and combined with flight hours as available to obtain ratings for all transparencies in helicopters used by the Army, Navy, and Air Force. The ratings are expressed on the

appropriate failure mode tables and in Figures 4 to 9. The left section of each figure shows a typical edge section with the code referencing the actual transparency location on the profile of each helicopter. Table 37 gives the part and federal stock numbers for each reference code. The percent-replaced figures are based on AVSCOM average monthly demand data and the total number of ships. A similar usage rate is based on quantity used and number of ships inspected at New Cumberland Army Depot. These ratings are:

$$\text{Percent Replaced (AVSCOM)} = \frac{12 \times \text{Average Monthly Demand}}{\text{Number of Aircraft}}$$

$$\text{Percent Replaced (Depot)} = \frac{\text{Number of Parts Replaced}}{\text{Number of Parts Inspected}}$$

The other three terms used in these figures and associated tables are defined as:

Mean Time Between Remove-Replace

$$\text{MTBRR} = \frac{\text{Flight Hours of Population} \times \text{No. Parts per Aircraft}}{\text{Number of Replacements}}$$

Mean Time Between Failure

$$\text{MTBF} = \frac{\text{Flight Hours of Population} \times \text{No. Parts per Aircraft}}{\text{Number of Failures}}$$

Mean Time Replace

$$\text{MTR} = \frac{\text{Total Time All Parts Replaced}}{\text{Number of Replacements}}$$

The difference between MTBRR and MTR is that MTBRR includes flight hours of nonfailure parts, whereas MTR gives the average time of the failures corrected by replacement. From the listed expressions, it is obvious that the MTBRR is concerned with replacement actions only for a particular part, whereas MTBF includes all failures reported regardless of action to correct the condition. Hence, MTBF would include actions such as replace, repair, and adjust compared to replacement only for MTBRR. Therefore, the MTBF figure should always be lower than MTBRR for a particular maintenance facility. Comparisons of these items for various services or facilities must be done with reservation, since the actions are quite subjective and dependent on spares availability. The situation of spares shortage would tend to yield higher MTBRR ratings. This circumstance would indicate some merit to the MTR rating that only addresses failures corrected by a replacement action. Supposedly, as the population reaches overhaul or service life limits, the MTR and MTBRR would agree.

TABLE 37. HELICOPTER TRANSPARENCY CODES

Model	Code	Part Number	FSN	Description
AH-1G	A	209-030-508-39	1560-454-0235	Fwd. W/S R/H
	A	209-030-515-49	1560-454-0255	Fwd. W/S L/H
	B	209-030-507-45	1560-454-0251	Rear W/S L/H
	B	209-030-516-51	1560-454-0256	Rear W/S R/H
	C	209-030-509		Center W/S
UH-1	A	204-030-666-44	1560-868-7003	W/S R/H
	A	204-030-666-43	1560-868-7004	W/S L/H
	B	204-030-673-3	1560-999-0307	Top Window
	B	204-030-673-15	1560-999-0308	Top Window
	C	204-030-657-19	1560-701-9923	Nose Assy. Window L/R
	C	204-030-657-20	1560-701-9924	Nose Assy. Window R/H
	D	204-030-459-1	1560-690-7285	Crew Window L/H
	D	204-030-459-2	1560-690-7286	Crew Window R/H
	E	204-030-770-1	1560-690-7288	Crew Door L/H
	E	204-030-770-2	1560-690-7289	Crew Door R/H
	F	204-030-799-1	1560-690-7290	Crew Door Wind. Assy.
	G	204-030-285-1	1560-987-5146	Window Panel L/H
	G	204-030-285-2	1560-987-5147	Window Panel R/H
	H	204-030-669-5	1560-633-0849	Window Assy.
	H	204-030-669-6	1560-672-0064	Window Assy.
	H	204-030-669-7	1560-967-1797	Window Assy.
OH-6	A	5001424	1560-133-6185	W/S L/H
	A	369A2404-601	--	W/S L/H
	A	5001425	1560-133-6229	W/S R/H
	A	369A2404-602	--	W/S R/H
	B	5001422	1560-133-6184	Lower W/S R/H
	B	369A2404-603	--	Lower W/S R/H
	B	5001423	1560-133-6186	Lower W/S L/H
	B	369A2404-604	--	Lower W/S L/H
	C	369A2420-1	1560-051-3558	Upper W/S L/H
	C	369A2420-2	1560-051-3726	Upper W/S R/H
	D	369A2046-1	1560-844-8207	Pilots Door L/H
	D	369A2046-2	1560-844-8259	Pilots Door R/H
	E	369A2047-1	1560-944-0513	Cargo Door L/H
	E	369A2047-2	1560-944-0354	Cargo Door R/H

TABLE 37 - CONTINUED

Model	Code	Part Number	FSN	Description
CH-47	A	114SS602-4	1560-944-2490	Center W/S
	B	114SS601-7	-	W/S L/H
	B	114SS604-1	1560-133-7157	W/S L/H
	B	114SS601-8	-	W/S R/H
	B	114SS604-2	1560-133-7158	W/S R/H
	C	114S1715-36	1560-420-7872	Chin Window R/H
	C	114S1715-35	1560-420-7873	Chin Window L/H
	D	114S1714-30	1560-756-5477	Top Window R/H
	D	114S1714-29	1560-756-5478	Top Window L/H
	E	114S1722-15	1560-869-8985	Sliding Window L/H
	E	114S1722-16	1560-869-8986	Sliding Window R/H
	E	114S1723-17	1560-869-8997	Sliding Window L/H
	E	114S1723-18	1560-869-8996	Sliding Window R/H
	F	114S1713-3	1560-885-0081	Lower Side Window L/H
	F	114S1713-4	1560-885-0059	Lower Side Window R/H
	G	114S2721-5	1560-949-8253	Crew Window
CH-54	A	6420-61328-102	1560-021-2729	Center W/S
	B	6420-61356-101	1560-902-4698	W/S L & R/H
	C	6420-61333-103	1560-934-8402	Eyebrow Window L/H
	C	6420-61333-104	1560-938-8359	Eyebrow Window R/H
	D	6420-61330-103	1560-902-4618	Corner Window L/H
	D	6420-61330-104	1560-902-4706	Corner Window R/H
	E	6420-61332-103	1560-934-8369	Lower Front Window L/H
	E	6420-61332-104	1560-934-8370	Lower Front Window R/H
	F	6420-61145-227	1560-902-4525	Upper Side Window L/H
	F	6420-61145-228	1560-902-4617	Upper Side Window R/H
	G	6420-61417-102	-	Side Window L & R/H
	H	6420-61705-104	1560-114-1260	Rear Side Window Upper
	I	6420-61705-101	-	Rear Side Window Lower
OH-58	A	206-031-115	-	W/S L/H
	A	206-032-115	1560-127-3179	W/S R/H
	B	206-031-116	-	Lower Nose Window L/H
	B	206-032-116	-	Lower Nose Window R/H
	C	206-031-108	-	Upper Window
	D	206-031-500	-	Pilot Door Window L/H
	D	206-032-500	-	Pilot Door Window R/H
	E	206-031-501	-	Cargo Door Window L/H
	E	206-032-501	-	Cargo Door Window R/H

FAILURE MODES AND RATINGS

CH-47 Transparency

Table 38 shows the failure modes and maintenance actions for the windshields on CH-47 helicopters under test at Fort Rucker. Three different time periods are shown with the total flight hours for two or three aircraft. The latest report (from July 1969 to September 1970) was mainly conducted to evaluate a new engine design. During this scheduled test period, the modified glass-faced windshield design was also evaluated. Poor results for the glass-faced design compared with previous plastic laminated windshields are indicated by the MTBRR ratings. Seven of eleven replacements of new type panels were attributed to scratches, compared with one in the previous program. The possibility of improperly marked parts was brought to the attention of Boeing-Vertol personnel. However, Boeing substantiated their information as valid. Maintenance personnel at Fort Rucker, Test Board indicated that no glass-glass laminated CH-47 windshields have been replaced for scratches. The fact that two different designs (glass-plastic and glass-glass laminates) carry the same part and federal stock number could be a possible explanation for this discrepancy. Such a condition makes evaluation of various modifications more difficult. Thus, due to the conflicting information and the small sample size for this helicopter, the indications cannot be construed to be representative of the population. Nonetheless, the data can be used to arrive at an average replacement time of 4.5 hours.

Except for leaking and installation type repairs, the windshields listed as glass-faced had no attempted repairs. Conversely, repair of scratches and cracks were attempted on the plastic panels. Such a difference would tend to indicate that the 1969-1970 test was conducted on glass-faced panels as shown. Possibly, the new modifications were mishandled, causing excessive scratches, or the inspection criteria were too critical.

Figure 4 presents all usage rates obtained for all CH-47 transparencies. The ratings appear to indicate that the special features as used in the windshields cause the main problem. The combination of wipers and heating causes a rather low MTBRR of 600 to 870.

Percent-replaced figures as reported for depot action indicate better than half of the transparencies are replaced. However, 95% of helicopters in for overhaul were based in Vietnam. This would explain the vast differences between replacement rates for non-windshield transparencies when compared with AVSCOM data. The depot replacements for these structures are considerably higher than AVSCOM values. Conversely, the replacement rates for depot action on windshields reflect AVSCOM percentages.

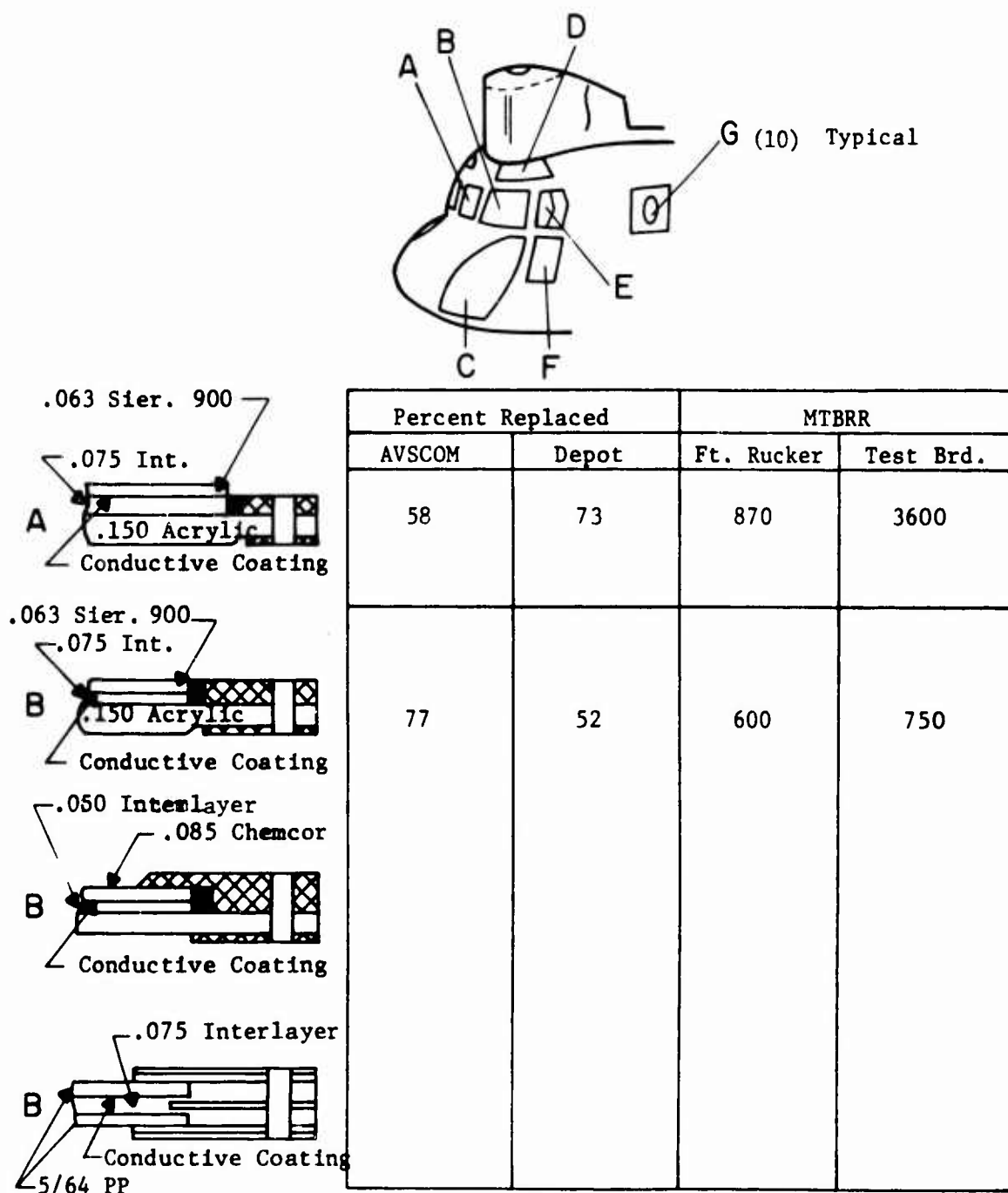


Figure 4. Service Performance of CH-47 Transparencies.

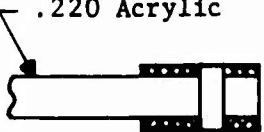
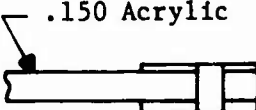
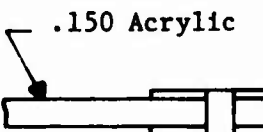
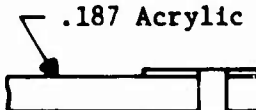
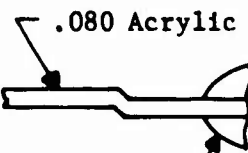
		Percent Replaced		MTBRR	
		AVSCOM	Depot	Ft. Rucker	Test Brd.
C		23	74	40,000	21,800
D		35	75	2,960	10,900
E		13	50	80,000	10,900
F		8	50	40,000	10,900
G		8	31	2,820	6,700
Flight Hours				20,054	10,896

Figure 4. Continued.

TABLE 38. FAILURE MODES AND MAINTENANCE ACTIONS
FOR CH-47 WINDSHIELD *

Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
July 1969 - September 1970		4,132 Hours		3 Aircraft	
114SS604-1	Leaking Loose	0	-	8	6.5
Left Hand	Delaminated	1	4.0	0	-
	Scratched	3	11.4	0	-
	Chipped	1	33.5	0	-
	Distorted	1	3.0	0	-
	114SS604-2	Leaking	0	-	5
Right Hand	Scratched	4	12.2	0	-
	Distorted	1	3.0	0	-
TOTALS		11	67.1	13	10.2
		MTBRR = 750		MTBF = 640	
114SS602-4	Leaking	0	-	1	0.2
Center	Delaminated	1	4.0	0	-
	Heating Failed	0	-	1	0.3
TOTALS		1	4.0	2	0.5
		MTBRR = 4130		MTBF = 1380	
April 1968 - June 1969		4,975 Hours		3 Aircraft	
114SS601-7	Leaking	0	-	1	1.5
Left Hand	Delaminated	2	4.0	0	-
	Scratched	1	2.0	1	0.5
	Heating Failed	1	1.3	0	-
	114SS601-8	Cracked	2	7.5	1
Right Hand	Scratched	1	4.2	2	14.0
	Heating Failed	1	4.0	0	-
TOTALS		8	23.0	5	17.0
		MTBRR = 1240		MTBF = 760	
114SS602-4	Loose	0	-	1	1.0
Center	Internal Failure	1	5.5	0	-
TOTALS		1	5.5	1	1.0
		MTBRR = 4980		MTBF = 2490	
* Source: Fort Rucker Test Board					
Supplied by: Boeing Company, Vertol Division					

TABLE 38 - CONTINUED					
Part Number	Condition	<u>Replaced</u>		<u>Repaired</u>	
		No.	MMHR	No.	MMHR
July 1967 - April 1968		1,789 Hours		2 Aircraft	
114SS601-7	Leaking	0	-	1	0.5
Left Hand	Broken	1	2.8	0	-
114SS601-8	Cracked	1	2.2	0	-
Right Hand					
TOTALS		2	5.0	1	0.5
		MTBRR = 1790		MTBF = 1290	

CH-46 Windshield

Table 39 shows the failure condition and replacement action for the right-hand (pilot) all plastic, heated windshield on the CH-46. The first tabulation for the summer months (April-August) indicates scratches to be the main problem with delamination fourth in total frequency. Although the failure modes maintained their relative distribution in the second tabulation that included winter months, a threefold increase in flight hours produced a sixfold increase in failure. The MTBRR of 1740 for the summer period dropped to 920. Although some new failure causes were apparent such as battle damage, the drastic increase in failures is attributed to the time span that included the winter months.

Twenty-eight of the 211 detailed failures were not corrected by a replacement action. All except four of these failures were mechanical types such as cracks, scratches, crazing, and combat damage. Hence, one could speculate that a reasonable portion of the 24 failures were corrected by a repair action.

CH-53 Transparencies

Failure modes and actions for each windshield on the CH-53 are presented on Table 40. In all cases, the design is identical, with heated plastic laminates (polyester-vinyl-stretched acrylic). The numbers replaced for specific reasons are shown for both the Air Force and the Navy. The time periods are not similar, but they do include a span of winter operation. On the basis of total flight hours, the frequency of replacement is almost identical. The Navy data shows about five times the replacements for five times the flight hours. The total MTBRR for both services was 780.

TABLE 39. FAILURE MODES AND REPLACEMENT ACTIONS
FOR CH-46 WINDSHIELD*

Part Number	Condition	Number	
		Reported	Replaced
April 1968 - August 1968		48,568 Hours	
A02SS801-2 Right	Cracked/Broken	5	5
	Delaminated	3	3
	Scratched	9	9
	Crazed	3	3
	Burned/Overheated	1	1
	Buckled/Distorted	5	5
	Deteriorated	<u>2</u>	<u>2</u>
TOTALS		28	28
		MTBRR = 1740	
July 1968 - December 1969		169,101 Hours	
A02SS801-2 Right	Cracked	28	26
	Broken	12	8
	Scratched	59	52
	Delaminated	21	20
	Crazed	48	43
	Distorted	14	14
	Deteriorated	4	4
	Burned/Overheated	7	7
	Battle Damage	13	9
	Nicked	1	0
	Pitted	1	1
	Leaking/Loose	<u>3</u>	<u>0</u>
TOTALS		211	134
		MTBRR = 920	
* Source: Navy 3-M Supplied by: Boeing Company, Vertol Division			

TABLE 40. FAILURE MODES AND MAINTENANCE ACTIONS
FOR CH-53 WINDSHIELD

Part Number	Condition	Replaced *		Repaired *		Replaced**
		No.	MMHR	No.	MMHR	Number
65206-01003-110 Right Hand	Leaking/Loose	0	-	1	2.5	0
	Cracked	0	-	1	5.3	10
	Broken	0	-	0	-	1
	Delaminated	2	14.3	0	-	21
	Scored	1	6.0***	1	6.0***	12
	Crazed	5	65.2	0	-	14
	Distorted	0	-	0	-	5
	Deteriorated	1	8.7	0	-	1
	Burned	0	-	0	-	1
	Internal Failure	1	9.0	0	-	0
	Coating Defect	0	-	1	1.7	0
TOTALS		10	103.2	4	15.5	65
		MTBRR = 1090		MTBF = 720		MTBRR=800
65206-01003-109 Left Hand	Leaking/Loose	0	-	5	5.4	0
	Cracked	1	6.2	0	-	4
	Broken	0	-	1	1.0	2
	Delaminated	5	70.7	0	-	23
	Scored	2	26.1***	2	26.1***	14
	Crazed	3	42.0	0	-	20
	Distorted	0	-	0	-	1
	Burned	4	28.0	0	-	0
	Coating Defect	0	-	1	0.5	0
	Bent/Binding	2	19.0	0	-	1
	TOTALS		17	192.0	9	33.0
		MTBRR = 600		MTBF = 390		MTBRR=800

*Source: AFM 66-1, July 1971 - December 1971, 10, 144 Hours
Supplied by: Eustis Directorate

**Source: 3M, April 1970 - December 1971, 52, 154 Hours
Supplied by: Sikorsky

***Hours estimated on basis of number of actions

TABLE 40 - CONTINUED						
Part Number	Condition	Replaced *		Repaired*		Replaced**
		No.	MMHR	No.	MMHR	Number
65206-01009-105 Center	Leaking/Loose	0	-	3	2.5	0
	Cracked	0	-	0	-	4
	Broken	0	-	0	-	1
	Delaminated	9	75.2	0	-	36
	Scored	0	-	0	-	8
	Crazed	3	26.0	0	-	15
	Distorted	0	-	0	-	5
	Deteriorated	0	-	1	6.0	0
	Burned	0	-	0	-	2
	Coating Defect	0	-	1	0.7	0
	Bent	1	9.0	0	-	-
TOTALS		13	110.2	5	9.2	71
		MTBRR = 780		MTBF = 560		MTBRR = 730
*Source: AFM 66-1, July 1971 - December 1971, 10, 144 Hours Supplied by: Eustis Directorate **Source: 3M, April 1970 - December 1971, 52, 154 Hours Supplied by: Sikorsky						

A significant difference is apparent when comparing the failure distribution for the center panel with the left/right windshields. Although delamination appears to be the major problem, scoring has a significant impact for the left/right windshields. This would be as expected, since the center panel does not have a wiper. Such can be considered as additional evidence, demonstrating that scratches are produced by wipers sweeping partially dry or dirty plastic surfaces.

Table 41 indicates that failure of other transparent structures in the CH-53 is the result of mechanical damage. Including missing parts, 41 of 47 failures are directly attributed to a mechanical mechanism.

TABLE 41. FAILURE MODES FOR CH-53 TRANSPARENCIES *							
Condition	Window (65206-)					Escape Hatch 03039/10028	Total
	01004 Overhead	01006 Lower	01007 Bottom	05003 Cabin	03035 Door		
April 1970-December 1971 52,154 Hours							
Broken	1	0	1	7	1	7	= 17
Cracked	0	0	1	6	0	3	= 10
Missing	0	0	0	9	0	1	= 10
Deteriorated	0	0	0	1	0	0	= 1
Distorted	2	0	1	1	0	1	= 5
Scored	1	0	2	0	0	0	= 3
Crazed	1	0	0	0	0	0	= 1
* Source: Navy 3M Supplied by: Sikorsky Aircraft							

CH/HH-3 Windshield

Table 42 indicates that the predominant failure modes of the H-3 windshields are delamination and scoring. At present, the majority of the Air Force H-3's have plastic monolithic stretched acrylic center panels and plastic laminated, heated or unheated, main windshields. According to Sikorsky, the H-3 started with heated laminated glass that was changed to the Air Force requirements. The presence of repairs for physical problems such as breaks, cracks, and crazing tends to show the use of plastic panels in Air Force helicopters. The MTBRR for this helicopter for pilot/copilot windshields (1040) is somewhat higher than for both the CH-47 and CH-53. According to Sikorsky, the 13 most recently delivered HH-3's assigned to Alaska have already reached the point of nonavailable spares.* This has occurred because of frequent replacement requirements.

The hours for replacement action recorded on Table 42 look unreasonably high. Some of this could be caused by the estimates required, since the source gives total hours for all actions per a failure mode.

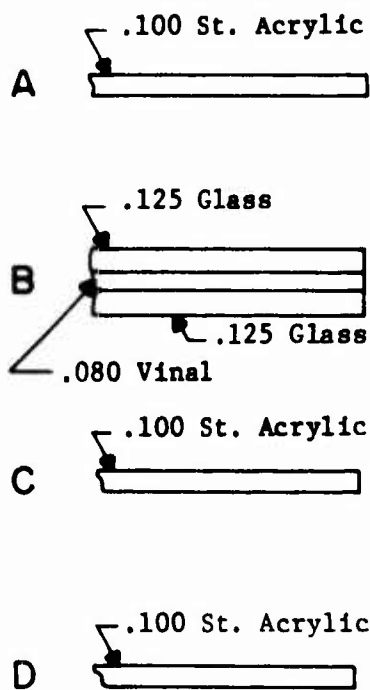
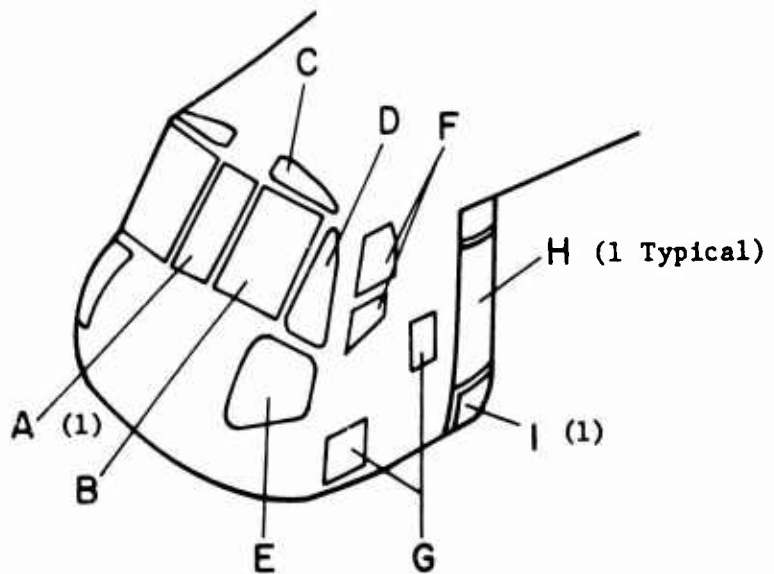
* Sikorsky Aircraft SSD 65N21C.1, 21 August 1972

TABLE 42. FAILURE MODES AND MAINTENANCE ACTIONS
FOR CH/HH-3C/E WINDSHIELD*

Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
July 1971 - December 1971		14,523 Hours			
1560-R203-418-4 Left/Right	Leaking	0	-	5	9.3
	Cracked	5	66.4 **	1	13.3 **
	Broken	2	4.3 **	1	2.2 **
	Delaminated	8	101.0	0	-
	Scored	8	59.0	0	-
	Crazed	3	19.0 **	1	6.3 **
	Deteriorated	0	-	1	1.6
	Internal Failure	1	9.0	0	-
	Shorted	1	8.6	0	-
	Bent	0	-	2	18.0
TOTALS		28	267.3	11	50.7
		MTBRR = 1040		MTBF = 740	
*Source: AFM 66-1 Supplied by: Eustis Directorate **Hours estimated on basis of number of actions - Source presents total hours for replacement and repair.					

CH-54 Transparencies

Results for the CH-54 windshield are rather sparse. The number of failures are very low compared to the estimated number of flight hours. In general, no comparative statements can be made for the glass-laminated main windshields and the stretched acrylic center panel. As shown by Table 43, all modes experienced are mechanical for these parts and the other transparencies, but scratching of the glass does not appear. However, it must be remembered that all three windshield parts are flat and unheated. Figure 5 tends to indicate satisfactory performance for all transparencies in the CH-54 helicopter, but actual usage has been minimal.



Percent Replaced AVSCOM	MTBRR	
	Ft. Rucker Usage	Company R&M
-	1400	16,000
3	1400	16,000
3	1400	96,000
2	1400	96,000

Figure 5. Service Performance of CH-54 Transparencies.

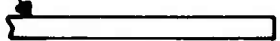
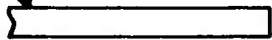
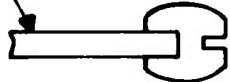

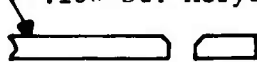
		Percent Replaced AVSCOM	MTBRR	
			Ft. Rucker Usage	Company R&M
E	 .100 St. Acrylic	6	1400	32,000
F	 .125 St. Acrylic	-	1400	8,800
G	 .100 St. Acrylic	-	1400	24,000
H	 .100 St. Acrylic	-	1400	48,000
I	 .100 St. Acrylic	-	1400	24,000
Flight Hours			1401	48,000

Figure 5. Continued.

TABLE 43. FAILURE MODES FOR CH-54 WINDSHIELD AND OTHER TRANSPARENCIES *		
Part Number	Condition	Number Replaced
Windshield	48,000 Hours	
6420-61356-101	Cracked	4
Left Hand	Pitted	2
6420-61328-101	Cracked	3
Center		
Lower Window		
6420-61332-	Cracked	1
	Broken	1
	Distorted	1
Side Window		
6420-61145	Cracked	19
	Broken	2
	Lost	1
Rear Bubble		
6420-61705-101	Cracked	1
	Hazy	1
* Source: Sikorsky Collection System		

UH-1 Transparencies

Failure modes for the monolithic acrylic windshield are all mechanical, as shown by Table 44. The majority of the parts are replaced because of breakage or cracks. Typically, replacements for scratches from the wipers occur as the third most frequent action. However, reference to Table 45 shows that the majority of complaints by inspection personnel are for scratches. The information on this table is consolidated from the detailed tabulations in Tables 46 through 50.

Table 45 presents an indication of potential problems or complaints for windshields on the UH-1 operating at Fort Rucker, Fort Benning, and Vietnam. Except for the helicopters operating in Vietnam, scratches are consistently the predominant failure requiring a replacement. About one-third (17/49) of the failures in Vietnam were caused by combat conditions. Twenty-seven of the remaining replacements were the result of windshields scored from wiper action.

TABLE 44. FAILURE MODES AND MAINTENANCE ACTIONS FOR UH-1 WINDSHIELD *					
Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
UH-1C					
204-030-666-043 Left Hand	Broken	13	180	0	-
	Cracked	15	180	0	-
	Battle Damage	6	114	0	-
	Scored	11	111	0	-
204-030-666-044 Right Hand	Broken	19	210	1	9
	Cracked	18	230	0	-
	Battle Damage	9	150	0	-
	Foreign Damage	5	27	0	-
	Scored	10	165	0	-
TOTALS		106	1367	1	9
UH-1D/H					
204-030-666-043	Broken	76	990	3	28
	Cracked	49	550	4	28
	Battle Damage	20	270	2	6
	Foreign Damage	16	140	1	4
	Chipped	33	480	0	-
	Scored	33	360	0	-
204-030-666-044	Broken	86	1250	3	23
	Cracked	48	590	1	20
	Battle Damage	35	480	3	30
	Foreign Damage	13	110	0	-
	Punctured	14	165	1	5
	Chipped	23	430	2	20
	Scored	44	525	0	-
TOTALS		490	6340	20	164
* Source: TAERS 2407 through October 1971					

TABLE 45. FAILURE MODES AND MAINTENANCE ACTIONS
FOR UH-1 WINDSHIELD AT VARIOUS BASES *

Base	Condition	Number		
		Reported	Replaced	Repaired
UH-1C		37,731 Hours		
Ft. Rucker	Scratched	31	2	29
	Leaked/Loose	<u>2</u>	<u>0</u>	<u>2</u>
TOTALS		33	2	31
		MTBRR = 37,700		MTBF = 2430
UH-1D		77,085 Hours		
Ft. Rucker	Cracked/Broken	1	1	0
	Scratched	11	0	11
Vietnam	Cracked/Broken	5	5	0
	Scratched	27	23	0 **
	Battle Damage	17	17	0
Ft. Benning	Cracked/Broken	3	- **	-
	Scratched	<u>21</u>	<u>-</u>	<u>-</u>
TOTALS		85	46	11
		MTBRR = 3350		MTBF = 2700
* Bell Helicopter UH-1/AH-1G Maintenance and Reliability Program DAAJ01-67-C-1588				
** No definition as to action.				

No repairs were attempted to remove scratches from helicopters stationed in Vietnam. Conversely, the actions to correct scratches at Fort Rucker were almost all along the repair lines. Repairs constituted 80 of 83 actions at Fort Rucker. As noted by Tables 46 and 47, many repairs had a short life, with second and third efforts to improve the surface quality.

TABLE 46. UH-1C WINDSHIELD PROBLEMS

Base: Ft. Rucker

Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
65-9491	161266	L W/S	463	Scratched	Wiper Abrasion	Replace
		R W/S	463	Scratched	Wiper Abrasion	Replace
	030267	L W/S	523	Scratched	Wiper Abrasion	Repair
		R W/S	523	Scratched	Wiper Abrasion	Repair
	100267	43	546	Scratched	Wiper Abrasion	Repair
	100267	44	546	Scratched	Wiper Abrasion	Repair
65-9492	050766	L W/S	201	Scratched	Unknown	Repair
		R W/S	201	Scratched	Unknown	Repair
	251066	44	378	Scratched	Wiper Abrasion	Repair
65-9493	110367	44	708	Scratched	Wiper Abrasion	Repair
		43	782	Scratched	Wiper Abrasion	Repair
	140667	L W/S	946	Scratched	Wiper Abrasion	Repair
		R W/S	946	Scratched	Wiper Abrasion	Repair
	220667	W/S	985	Scratched	Wiper Abrasion	Repair
65-9495	050167	L W/S	298	Scratched	Wiper Abrasion	Repair
		R W/S	298	Scratched	Wiper Abrasion	Repair
	160367	44	463	Scratched	Wiper Abrasion	Repair
		43	463	Scratched	Wiper Abrasion	Repair
65-9496	060566	44	105	Scratched	Unknown	Repair
65-9497	200267	44	527	Scratched	Wiper Abrasion	Repair
		43	527	Scratched	Wiper Abrasion	Repair
65-9501	150367	43	801	Scratched	Wiper Abrasion	Repair
65-9503	130766	43	198	Scratched	Unknown	Repair
		44	198	Scratched	Unknown	Repair
	160766	44	206	Scratched	Wiper Abrasion	Repair
		43	206	Scratched	Wiper Abrasion	Repair
	221166	43	499	Scratched	Unknown	Repair
		44	499	Scratched	Unknown	Repair
65-9501		43	604	Scratched	Unknown	Repair
		44	604	Scratched	Unknown	Repair
65-9470	260566	W/S	218	Leaked	Unknown	Repair
65-9502	050666	49	96	Loose	Unknown	Repair
65-9470	160167	-44	600	Scratched	Unknown	Repair
		-43	600	Scratched	Unknown	Repair
	100267	-44	648	Scratched	Wiper Abrasion	Repair
		43	648	Scratched	Wiper Abrasion	Repair

TABLE 46 - Continued

Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
65-9471	200267	44	668	Scratched	Wiper Abrasion	Repair
		43	668	Scratched	Wiper Abrasion	Repair
	160267	44	403	Scratched	Wiper Abrasion	Repair
		43	403	Scratched	Wiper Abrasion	Repair
65-9472	050466	43	94	Scratched	Wiper Abrasion	Repair
		44	94	Scratched	Wiper Abrasion	Repair
	020766	43	307	Scratched	Wiper Abrasion	Repair
		44	307	Scratched	Wiper Abrasion	Repair
	131066	49	510	Scratched	Wiper Abrasion	Repair
		39	510	Scratched	Wiper Abrasion	Repair
	100167	L W/S	714	Scratched	Wiper Abrasion	Repair
		R W/S	714	Scratched	Wiper Abrasion	Repair
	080267	44	792	Scratched	Wiper Abrasion	Repair
		43	792	Scratched	Wiper Abrasion	Repair
65-9473	010466	44	105	Scratched	Unknown	Repair
	110866	44	280	Scratched	Wiper Abrasion	Repair
		43	280	Scratched	Wiper Abrasion	Repair
	061165	43	508	Scratched	Wiper Abrasion	Repair
	081166	44	509	Scratched	Wiper Abrasion	Repair
	161266	43	610	Scratched	Unknown	Repair
		44	610	Scratched	Unknown	Repair
65-9490	090766	43	199	Scratched	Wiper Abrasion	Repair
		44	199	Scratched	Wiper Abrasion	Repair
	300866	43	274	Scratched	Unknown	Repair
		44	274	Scratched	Unknown	Repair
	050667	L W/S	800	Scratched	Wiper Abrasion	Repair
		R W/S	800	Scratched	Wiper Abrasion	Repair
	120766	43	204	Scratched	Unknown	Repair
		44	204	Scratched	Unknown	Repair
	151166	43	379	Scratched	Wiper Abrasion	Repair
		44	381	Scratched	Wiper Abrasion	Repair
	131266	L W/S	462	Scratched	Wiper Abrasion	Repair
		R W/S	462	Scratched	Wiper Abrasion	Repair

TABLE 47. UH-1D WINDSHIELD PROBLEMS

Base: Ft. Rucker

Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
65-10096	071266	044	322	Broken	Unknown	Replaced
65-10097	160567	044	804	Scratched	Unknown	Repaired
		043	804	Scratched	Unknown	Repaired
	090667	044	880	Scratched	Unknown	Repaired
		043	880	Scratched	Unknown	Repaired
65-10098	300667	044	813	Scratched	Unknown	Repaired
		043	813	Scratched	Unknown	Repaired
65-10099	050667	W/S	861	Scratched	Unknown	Repaired
66-1039	010467	044	300	Scratched	Wiper Abrasion	Repaired
		043	300	Scratched	Wiper Abrasion	Repaired
66-1041	160567	044	444	Scratched	Wiper Abrasion	Repaired
		043	444	Scratched	Wiper Abrasion	Repaired
	310567	044	496	Scratched	Wiper Abrasion	Repaired
		043	496	Scratched	Wiper Abrasion	Repaired

TABLE 48. UH-1D WINDSHIELD PROBLEMS

Base: Viet Nam

Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
66-816	210467	44	345	Broken	Accident	Replace
62-2107	061266	32	1506	Cracked	Landing	Replace
63-8846	121066	31	1286	Cracked	Unknown	Replace
64-13510	040966	32	1191	Cracked	Unknown	Replace
66-16045	300767	44	498	Cracked	Unknown	Replace
62-12359	081166	44	1509	Scratched	Wiper Abrasion	Replace
	081166	43	1509	Scratched	Wiper Abrasion	Replace
63-8745	221166	32	1304	Scratched	Wiper Abrasion	Nothing
		31	1304	Scratched	Wiper Abrasion	Nothing
	151266	31	1346	Scratched	Wiper Abrasion	Replace
	281266	31	1387	Scratched	Wiper Abrasion	Replace
63-8785	171166	32	1496	Scratched	Wiper Abrasion	Replace
		31	1496	Scratched	Wiper Abrasion	Replace
63-8794	180966	32	1548	Scratched	Wiper Abrasion	Replace
		31	1548	Scratched	Wiper Abrasion	Replace
63-8796	271266	32	1713	Scratched	Wiper Abrasion	Replace
		31	1713	Scratched	Wiper Abrasion	Replace
63-8797	011166	43	1319	Scratched	Wiper Abrasion	Replace
		32	1319	Scratched	Wiper Abrasion	Replace
63-8810	180466	31	979	Scratched	Wiper Abrasion	Nothing
		32	979	Scratched	Wiper Abrasion	Nothing
	091166	32	1409	Scratched	Wiper Abrasion	Replace
		31	1409	Scratched	Wiper Abrasion	Replace
63-8819	030167	44	1473	Scratched	Wiper Abrasion	Replace
63-8822	271066	44	1216	Scratched	Wiper Abrasion	Replace
63-8825	021266	44	1204	Scratched	Wiper Abrasion	Replace
63-8836	181266	44	1206	Scratched	Wiper Abrasion	Replace
63-8837	271066	44	1079	Scratched	Wiper Abrasion	Replace
	131066	43	1079	Scratched	Wiper Abrasion	Replace
63-8846	061166	32	1293	Scratched	Wiper Abrasion	Replace
	200167	31	1494	Scratched	Wiper Abrasion	Replace
63-12961	030267	43	1605	Scratched	Wiper Abrasion	Replace
		44	1605	Scratched	Wiper Abrasion	Replace
64-13625	180766	32	786	Scratched	Wiper Abrasion	Replace
		31	786	Scratched	Wiper Abrasion	Replace
64-13740	081166	44	1129	Scratched	Wiper Abrasion	Replace
64-13849	221266	32	984	Scratched	Wiper Abrasion	Replace
		31	984	Scratched	Wiper Abrasion	Replace

TABLE 48 - Continued

Aircraft S/N	Date (D'Y)	Part No.	Flight Hours	Complaint	Cause	Action
62-12358	030966	032	1277	Holes	Shrapnel Damage	Replace
		031	1277	Holes	Shrapnel Damage	Replace
62-12372	060566	032	1330	Holes	Ground Fire	Replace
		031	1330	Holes	Ground Fire	Replace
	030966	032	1586	Holes	Shrapnel Damage	Replace
		031	1586	Holes	Shrapnel Damage	Replace
63-8751		032	1245	Holes	Shrapnel Damage	Replace
		031	1245	Holes	Shrapnel Damage	Replace
63-12958		032	1102	Holes	Shrapnel Damage	Replace
		031	1102	Holes	Shrapnel Damage	Replace
63-12960		032	1102	Holes	Shrapnel Damage	Replace
		031	1102	Holes	Shrapnel Damage	Replace
66-1004	070767	044	446	Broken	Ground Fire	Replace
66-16045	160767	043	449	Broken	Ground Fire	Replace
		044	449	Broken	Ground Fire	Replace
64-14164	080966	044	477	Broken	Shrapnel Damage	Replace
66-597	010767	044	716	Broken	Shrapnel Damage	Replace

TABLE 49. UH-1D WINDSHIELD PROBLEMS

Base: Ft. Benning

Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
62-12352	040864	32	480	Broken	Flying Debris	
		31	480	Broken	Flying Debris	
63-8757	161064	32	413	Broken	Flew into Wires	
62-2109	010864	32	396	Scratched	Wiper Abrasion	
	080265	32	701	Scratched	Wiper Abrasion	
62-2110	110964	32	607	Scratched	Wiper Abrasion	
62-2111	290465	32	463	Scratched	Wiper Abrasion	
62-2113	010864	32	449	Scratched	Wiper Abrasion	
62-12351	181064	32	532	Scratched	Wiper Abrasion	
	300165	32	604	Scratched	Wiper Abrasion	
	200765	32	800	Scratched	Wiper Abrasion	Replace
62-12354	061064	32	559	Scratched	Wiper Abrasion	
	010565	32	745	Scratched	Wiper Abrasion	
62-12358	090964	32	350	Scratched	Wiper Abrasion	
62-12362	180864	32	334	Scratched	Wiper Abrasion	
	180364	32	569	Scratched	Wiper Abrasion	
62-12369	070265	32	642	Scratched	Wiper Abrasion	
62-12372	161064	32	526	Scratched	Wiper Abrasion	
	050465		654	Scratched	Wiper Abrasion	
63-8740	240664	32	272	Scratched	Wiper Abrasion	
	250864	32	363	Scratched	Wiper Abrasion	
	050465	32	586	Scratched	Wiper Abrasion	
63-8743	211064	32	315	Scratched	Wiper Abrasion	
63-8749	150964	32	370	Scratched	Wiper Abrasion	
63-8750	060465	32	602	Scratched	Wiper Abrasion	
63-8752	300764	32	388	Scratched	Wiper Abrasion	
63-8755	220165	32	598	Scratched	Wiper Abrasion	
	190265	32	654	Scratched	Wiper Abrasion	
63-8761	040864	32	245	Scratched	Wiper Abrasion	
	171064	32	399	Scratched	Wiper Abrasion	
	110365	32	602	Scratched	Wiper Abrasion	
	090565	32	648	Scratched	Wiper Abrasion	
63-8762	140964	027	377	Scratched	Wiper Abrasion	
	260165	032	546	Scratched	Wiper Abrasion	
63-8769	150365	032	612	Scratched	Wiper Abrasion	
63-8820	040265	032	444	Scratched	Wiper Abrasion	
	170265	032	472	Scratched	Wiper Abrasion	
	280665	032	634	Scratched	Wiper Abrasion	Replace

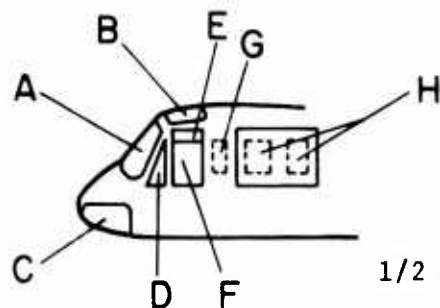
TABLE 50. AH-1G WINDSHIELD PROBLEMS						
Base: Hunter						
Aircraft S/N	Date (DMY)	Part No.	Flight Hours	Complaint	Cause	Action
66-15253	090967	509	139	Hole	Unknown	Nothing
66-15269	160568	509	370	Hole	Unknown	Repaired
	301068	509	749	Broken	Bird Strike	Replaced
66-15278	071168	509	911	Hole	Rocket Debris	Replaced
66-15315	051069	509	1199	Scratched	Unknown	Replaced
66-15321	291069	509	1431	Hole	Misuse	Repair
67-15469	251068	509	704	Crack	Misuse	Repair
67-15504	281069	509	1222	Broken	Unknown	Replace
67-15614	131069	509	1137	Broken	Unknown	Replace
67-15816	020669	509	418	Hole	Rocket Blast	Replace
68-15041	180669	509	117	Hole	Shrapnel Damage	Replace

Similar failure modes are shown by Table 51 for windshields in the UH-1 helicopter used by the Air Force. Although the population and time span are rather small, the replacement rate is rather low for the windshield. However, inclusion of the repairs, which mainly address cracks, reduces the MTBRR from 10,700 to 2380 (MTBF).

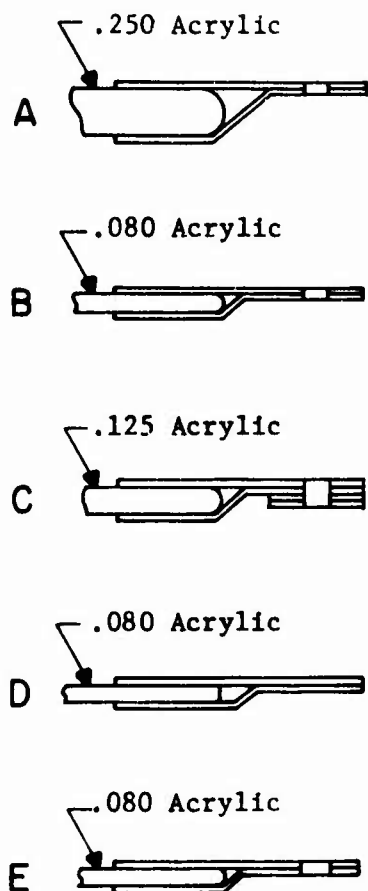
TABLE 51. FAILURE MODES AND MAINTENANCE ACTIONS FOR UH-1 WINDSHIELD *					
Part Number	Condition	<u>Replaced</u>		<u>Repaired</u>	
		No.	MMHR	No.	MMHR
July 1971 - December 1971 UH-1F		21,439 Hours			
204-030-666 Left/Right	Loose	0	-	1	1.0
	Cracked	1	4.5	10	44.5**
	Broken	1	3.4	1	3.4**
	Delaminated	0	-	1	8.0
	Scored	1	3.0	1	3.0**
	Crazed	1	8.0	0	-
TOTALS		4	18.9	14	59.9
		MTBRR = 10,700 MTBF = 2380			
* Source: AFM 66-1					
** Hours estimated on basis of number actions per mode.					

TABLE 52. FAILURE MODES AND MAINTENANCE ACTIONS
FOR UH-1 TRANSPARENCIES

Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
<u>Chin Bubble</u>					
204-030-657-019	Broken	65	790	7	65
	Cracked	19	210	6	60
	Battle Damage	24	390	5	30
	Crash	4	50	0	-
	Chipped	8	100	0	-
TOTALS		120	1540	18	155
204-030-657-020	Broken	90	1050	10	74
	Cracked	22	280	0	-
	Battle Damage	25	390	3	7
	Burned	2	30	0	-
	Chipped	2	21	0	-
	Scored	2	4	0	-
TOTALS		143	1775	13	81
<u>Roof Window</u>					
204-030-673-	Broken	31	234	0	-
	Cracked	15	160	0	-
	Battle Damage	3	13	1	34
	Scored	1	4	0	-
TOTALS		50	411	1	34
<u>Triangular Door Window</u>					
204-030-459	Broken	36	200	1	1.5
	Cracked	12	70	0	-
	Battle Damage	10	99	0	-
TOTALS		58	369	1	1.5
<u>Door Window</u>					
204-030-770-	Broken	62	310	8	32
	Cracked	21	50	5	12
	Battle Damage	10	30	0	-
TOTALS		93	390	13	44
* Source: TAERS 2407					



1/2 of components shown



Percent Replaced AVSCOM	MTBRR		MTR
	Ft. Rucker Usage	Company R&M	
15	6000	3960	500* 650** 1140
4	5500	-	-
14	6400	4900	940
4	6600	38,000	410
15	2000	-	-

* Special Study - UH-1D Windshield Replacement Repair Systems
Engineering Directorate, AVSCOM, Oct. 12, 1970.

** UH-1H Windshield Replacement, Reference Code 0501.

Figure 6. Service Performance of
UH-1 Transparencies.

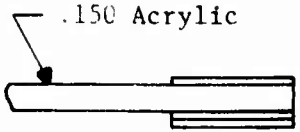
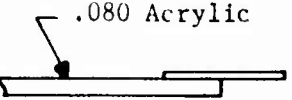
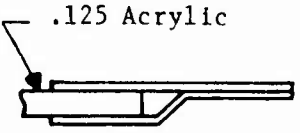
	Percent Replaced AVSCOM	MTBRR		MTR
		Ft. Rucker Usage	Company R&M	
F 	22	2000	2240	740
G 	3	19,000	22,400	950
H 	6	22,800	45,000	993
Flight Hours	-	193,228	112,816	-

Figure 6. Continued.

Replacement of the other transparencies in the UH-1 was normally associated with mechanical damage. In general, breaks, cracks, and battle damage constitute the bulk of the failure modes. Additional data on the UH-1 transparent non-windshield structures tabulated in Table 52 show the same general trend.

Figure 6 tends to indicate that there are no problems associated with transparent structures on the UH-1 helicopter. The highest usage (lowest MTBRR) appears for the door windows, followed by the windshield. However, the number of windshields that are beyond reasonable quality and remain in service is not known. Inspection of UH-1 windshields at random at Fort Rucker showed that a majority of the panels had excessive scratches but were rated as acceptable by the inspector. Hence there was an attitude of, Why replace because it will happen again? The writer estimates that 50% of the windshields (4 of 8) inspected were scratched beyond use. Tables 46 through 50 indicate that the average time to a replacement action for scratches was some 400 hours after initial complaint and documentation.

UH-2 Transparencies

Failures which required a replace action of glass-laminated windshields in the UH-2 were strictly mechanical. All seven failures listed were cracks or breaks. Although this helicopter uses heated laminated glass windshields, no failures of delamination or heating malfunction were reported for 1971, as shown by Table 53. Also, replacement for scratches or scoring by the wiper action was completely absent. According to Kaman personnel, no such problem exists for their laminated glass parts. Failure modes for other parts are all mechanical as shown by Table 54.

TABLE 53. FAILURE MODES AND MAINTENANCE ACTIONS FOR UH-2 WINDSHIELD *					
Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
Year - 1971	22, 170 Hours	112 Aircraft			
Windshield	Leaking/Loose	0	-	8	10.0
K633035-85/86	Cracked	0	36.7	0	-
Left/Right	Pitted	0	-	0	-
	Broken	1	4.5	0	-
TOTALS		7	41.2	8	10.0
* Source: Navy 3M Supplied by: Kaman Aerospace					

TABLE 54. FAILURE MODES AND MAINTENANCE ACTIONS
FOR UH-2 TRANSPARENCIES

Part Number	Condition	Replaced		Repaired	
		No.	MMHR	No.	MMHR
Year ~ 1971 112 Aircraft		22,170 Hours			
Corner Window	Broken	8	34.3	0	-
K633033-3/5/107	Loose/Leaking	0	-	3	2.0
	Deteriorated	0	-	1	1.5
	Cracked	24	50.0	0	-
TOTALS		32	84.3	4	3.5
		MTBRR = 1385		MTBF = 1230	
Roof Windows	Broken	32	212.0	0	-
K633034-205/207	Leaking	0	-	11	10.1
	Cut	0	-	1	1.0
	Alignment	0	-	1	0.5
	Cracked	39	175.0	0	-
TOTALS		71	387.0	13	11.6
		MTBRR = 620		MTBF = 530	
Lower Side Windows	Broken	21	84.0	0	-
K633036-101/105	Cracked	39	105.0	0	-
	Leaking	0	-	1	1.0
TOTALS		60	189.0	1	1.0
		MTBRR = 740		MTBF = 730	
Door Windows	Broken	37	219.0	0	-
K633010-17/101	Cracked	33	120.0	0	-
K633020-15	Loose	0	-	2	1.5
	Lost	1	3.8	0	-
TOTALS		71	342.8	2	1.5
		MTBRR = 620		MTBF = 610	
Cabin Window	Broken	11	49.0	0	-
K631070	Cracked	11	100.0	0	-
K633015	Loose	0	-	1	1.0
	Lost	1	12.0	0	-
TOTALS		23	161.0	1	1.0
		MTBRR = 3860		MTBF = 3700	
* Source: Navy 3M					
Supplied by: Kaman Aerospace					

OH-58 Transparencies

Other than three failure reports (two scratches and one breakage) obtained from AVSCOM Equipment Improvement Reports (EIR's), no failure modes were determined for the OH-58. Figure 7 indicates high usage (low MTBRR) for the windshield. However, the flight hours and numbers involved are small so the sampling could be a poor representation of the population. Inspection of eight parts at random at Fort Rucker disclosed four in service with excessive scratches and two with light sweeping scratches. These sweeping scratches were most likely caused by improper cleaning.

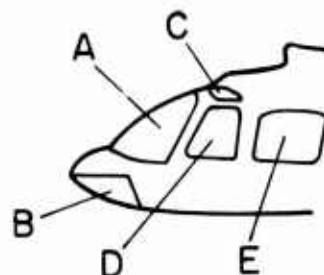
OH-6 Transparencies

Based on a survey of EIR's at AVSCOM, ten total windshield structures, either main or lower, have been replaced for cracking. One instance for distortion is on record. Figure 8 indicates that the prime areas for concern for the OH-6 are the lower windshield and upper window. According to Hughes Engineering, excessive venting occurred at the lower outside corner of the lower windshield. This was attributed to the fast curvature change at this location and was subsequently corrected by addition of a bonded doublet.

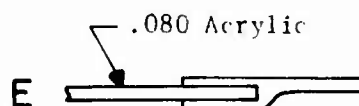
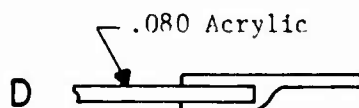
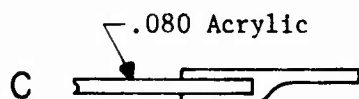
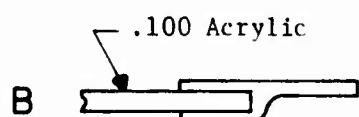
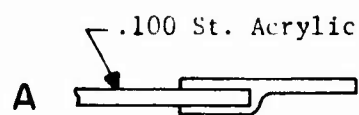
AH-1G Cockpit Windows

Table 55 shows a failure mode survey for all cockpit windows in the AH-1G. In general, the primary failure mode is breakage restricted to the cockpit door windows and the center panel. The majority of the cockpit door problem could be caused by sudden twisting, etc., occurring during crew access. Nonetheless, Figure 9 indicates moderately high usage rates for the AH-1G stretched acrylic windshields (especially, the center panel which uses a hot air rain removal system). Five actual cases are on record at AVSCOM defining excessive distortion or melting caused by hot air rain removal malfunction.

TABLE 55. FAILURE MODES AND MAINTENANCE ACTIONS FOR AH-1G COCKPIT TRANSPARENCIES					
Condition	Number Windshields Replaced (209-030-)				
	507 Left Rear	508 Right Fwd	509 Center	515 Left Fwd	516 Right Rear
Broken	12 (3)	12 (2)	20 (4)	3 (1)	2 (1)
Cracked	3 (2)	4 (7)	6	3 (2)	1
Foreign Obj. Dam.	1	2	2	1	0
Battle Damage	2 (7)	3	5	2	1 (1)
Burned	1	-	-	2	2
Chipped	1	6 (1)	11	3	2
* Source: TAERS 2407 through October 1971					
() = Failures corrected by repair action.					



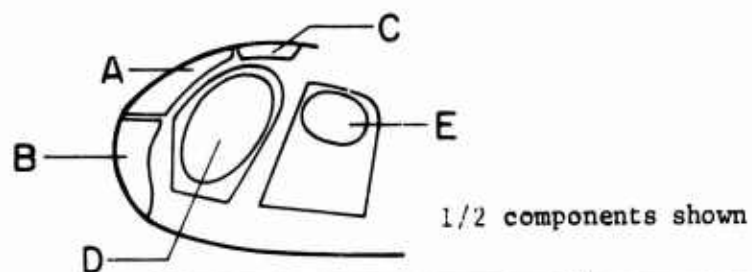
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	Percent Replaced AVSCOM	MTBRR Ft. Rucker Usage	MTR EIR'S*
A	4	880	552
B	-	8000	
C	-	1700	
D	4	1980	530
E	4	3000	
Flight Hours		23,756	

* Equipment Improvement Reports, Project Office, AVSCOM

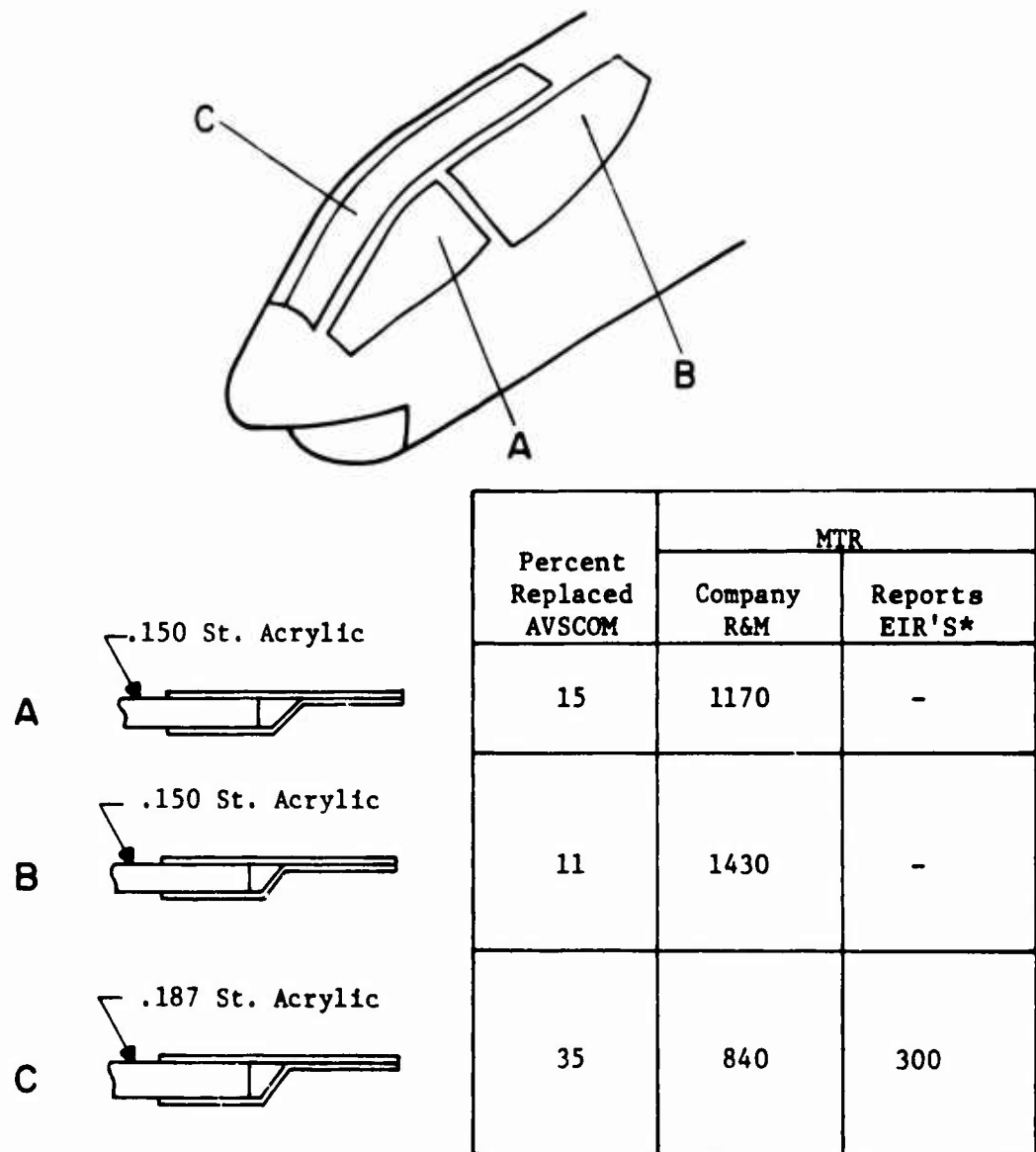
Figure 7. Service Performance of OH-58 Transparencies.



	Percent Replaced AVSCOM	MTBRR		MTR
		Ft. Rucker Usage	Company Usage*	
A .090 Polycarbonate	-	5850	3660	520
A .090 St. Acrylic				
B .090 Polycarbonate	14	1460	2100	260
B .090 St. Acrylic				
C .080 Acrylic	20	360	3100	350
D .040 Polycarbonate	1	1950	1940	520
E .060 Acrylic	4	2340	1430	-
Flight Hours		5853	126,500	

* Commercial Usage of Helicopter Transparencies, Hughes Tool Company, Dec. 17, 1971.

Figure 8. Service Performance of OH-6 Transparencies.



* Equipment Improvement Reports, Project Office, AVSCOM.

Figure 9. Service Performance of AH-1G Helicopter Transparencies.

TABLE 56. SERVICE PERFORMANCE OF CARGO WINDSHIELDS WITH
COMPARISON BETWEEN ARMY AND OTHER SERVICE
HELICOPTERS

Special Transparency Features	Army Helicopters		Other Service Helicopters		
	Type	MTBRR	Type	MTBRR	MTBF*
Deice, Wipers	CH-47	600	CH-46 (N)	920	1580
		750	CH-53 (N)	800	
			HH-53 (AF)	750	
Deice Only	CH-47 CTR	870	CH-53 CTR	735	1580
			CH-46 CTR		
Wipers Only	CH-54	1,400			
None	CH-54 CTR	1,400			
Averages					
Deice, Wipers		735		820	1235
Deice		870		735	1580
Wipers		1,400			
None		1,400			
*Source: 3-M					
Supplied by: NASC, Washington, D.C.					

CARGO WINDSHIELD SUMMARY

Table 56 consolidates all previous tables and illustrates the increased usage (low MTBRR-high replacement) for windshields with complexity of design experienced on cargo type helicopters. The more special features are incorporated in the windshields, the higher the frequency of failure. Additional information for similar windshields in use by the Navy and Air Force helicopters tend to show the same trend. In fact, the MTBRR ratings are quite similar except for the Navy data acquired from Naval Air Systems Command (NASC), which is expressed as MTBF. Since actual failure modes were not available for this information, definite statements are not practical. Elimination of the NASC data causes the other service averages to correspond with the Army.

TABLE 57. SERVICE PERFORMANCE OF WINDSHIELDS IN ARMY
UTILITY, ATTACK, AND OBSERVATION HELICOPTERS

Helicopter	Special Features	MTBRR	MTR
<u>Utility</u>			
UH-1	Wipers	6,000	1,140
		3,960	650
			500
UH-2*	Wipers, Deice	6,330	
Average		4,980	720
<u>Attack</u>			
AH-1G CTR	Hot Air Rain Removal		840
AH-1G	None		1,300
Average			1,070
<u>Observation</u>			
OH-6 Main		5,800	520
OH-6 Lower		1,460	260
OH-58		880	550
Average		2,710	440
* Non-Army Helicopter			

UTILITY, ATTACK, OBSERVATION WINDSHIELDS SUMMARY

The performance of the remaining windshields as shown by Table 57 do not exhibit any particular trend. The high MTBRR of the UH-1 windshield is surpassed somewhat by even higher rating for the UH-2. This is quite surprising since the UH-2 windshield has all the special features found on normal cargo type windshields. The UH-2 uses a laminated, heated glass windshield compared with the monolithic acrylic of the UH-1 windshield. Although acrylic is susceptible to scratching the MTBRR's of 3960 and 6000 are high. This can be explained by a lack of spares that limit replacement of inferior parts. The low MTBRR (880) for the OH-58 windshields without wipers tends to substantiate this reasoning. Also repeated complaints were obtained about scratches on acrylic windshields. Sweeping scratches were evident on both surfaces of the majority of acrylic windshields inspected at random. Although some of

these scratches were rather light, they do indicate that acrylic can be easily damaged during cleaning, especially when appropriate solvents and extra precautions to remove residual dirt are not used.

The performance of the AH-1G transparencies show a trend consistent with the cargo windshields higher replacement rates for the transparency with special features. On the basis of MTR, the center window which has a hot air rain removal system, was replaced some 460 hours sooner than the remaining panels that include access doors. However, the lack of any MTBRR data makes it difficult for any comparisons with other aircraft.

The MTBRR ratings for the observation helicopters show a range from a high of 5800 for the main OH-6 windshield to a low of 880 for the OH-58 windshield. No explanation is available for this since special features are not involved and the construction are monolithic acrylic. The possibility that the more recent OH-58 helicopter has a more critical inspection does exist. Consequently, the OH-6 is used with inferior windows compared with the OH-58.

OTHER (NONWINDSHIELD) TRANSPARENCIES

The performance of cockpit windows (Table 58) and cabin windows (Table 59) indicate no predominant problems. Therefore, it would appear that the materials now used for these applications (acrylic and some polycarbonate) are satisfactory.

INTERVIEWS

In an attempt to obtain first-hand knowledge and information about the various types of failure modes of helicopter transparencies, a number of military bases were visited. At each facility interviews were conducted with maintenance personnel and pilots in an effort to appraise the predominance of failures and problems that are encountered in the field. A secondary objective was to "search out the scrap piles" to locate samples of transparencies removed from service so that a failure mode analysis could be performed.

As an orderly means of gathering the information, a questionnaire was formulated, and after some discussion, certain personnel were asked to answer the questions. Figure 10 presents a sample of the questionnaire. Since the list of questions were intended to gather information for other parts of this report, some do not apply to failure modes. A summary of the answers received follows.

TABLE 58. SERVICE PERFORMANCE OF COCKPIT
WINDOWS IN ARMY HELICOPTERS

Helicopter	Window Type	MTBRR	MTR
<u>Cargo</u>			
CH-47	Upper	2,960	
	Lower	21,800	
	Door	10,900	
CH-54	Eye brow		
	Lower	32,000	
	Side		
	Door	4,400	
Average		14,400	
<u>Utility</u>			
UH-1	Roof	5,500	
	Lower	4,900	
		6,400	
	Door	2,240	
		2,000	
UH-2*	Roof	625	
Average		3,610	
<u>Observation</u>			
OH-6	Roof	3,100	
		360	350
OH-58	Door	1,950	
	Roof	1,700	
	Lower	8,000	
	Door	1,980	530
Average		2,860	440
* Non-Army			

TABLE 59. SERVICE PERFORMANCE OF CABIN
WINDOWS IN ARMY HELICOPTERS

Helicopter	MTBRR	MTR
<u>Cargo</u>		
CH-47	2,820	
	6,700	
Average	4,760	
<u>Utility</u>		
UH-1 Window	19,000	
Door	22,800	
Average	20,900	
<u>Observation</u>		
OH-6 Door	2,340	
OH-58 Door	3,000	
Average	2,620	

Question No. 1

Table 60 shows which of the listed failure modes were judged to be the most predominant for the helicopter cockpit windshield. The first column gives the percentage of the personnel who listed that mode as No. 1 and the second column the percentage who listed that mode as No. 2.

TABLE 60. PREDOMINANT FAILURE MODES

	<u>Percentage</u>	
	Number 1	Number 2
Scratches	61	25
Cracking and Breaking	2	4
Cleaning Problems	4	12
Solvent Attack	0	6
Distorted Vision	10	20
Mistreatment	8	4

This questionnaire relative to experience with CH-47 CH-46 CH-53
CH-54 UH-1 AH (CIRCLE ONE)

1. How would you rank different failure modes of main cockpit windshields in order of decreasing frequency (give the most predominant type of failure a number one (1) rating through the type of failure which is encountered the least number of times).

_____ Scratches

_____ Cracking and Breaking

_____ Deice Failure

_____ Cleaning Problems

_____ Attack of Solvents

_____ Distorted Vision

_____ Mistreatment

_____ Other

2. What are the two most common failure modes of windows other than main cockpit windshields?

1. _____

2. _____

3. Do you know of a particular case where a windshield or window failure has affected the safety of the flight? _____

Figure 10. Sample Questionnaire

4. Is there any indication that a certain type of mission or geographical location experiences a higher windshield usage rate? Explain.

5. Do you feel that helicopter windshields and windows should have deicing capability? _____

6. Which of the problems listed in Question No. 1 do you think are being "lived with" only because they have existed for such a long period of time, but definitely require a solution? _____

7. Are prescribed methods for maintaining (cleaning, repair) transparencies documented in T.O.? _____

8. If prescribed methods are available, are they used and adhered to? _____

9. Are prescribed methods practical and easy in your opinion? _____

Figure 10. - Continued

10. What methods of your own not prescribed do you use to maintain transparencies? _____

11. What are the major problems associated with maintenance of transparencies in your opinion? _____

12. Other Comments: _____

Signature

Title and Division

Please return to: PPG Industries, Inc.
State National Bank Building
Suite 777
Huntsville, Alabama 35801
Attention: R. L. Malobicky, Jr.

Figure 10. - Continued.

In addition to those failure modes listed, there were a few additional modes listed in the "other" category: delamination, crazing, and reflections.

By far, the primary objection to the cockpit windshield performance was scratches! This problem is so acute that windshield wipers are not turned on even in severe weather conditions except in an extreme emergency. The following quotations were taken from the questionnaires to illustrate this point:

USMC Captain/Pilot (CH-46)

"Used personnel with head out the windows to see in rain rather than use wipers. Wipers used in total only 2 or 3 times."

This pilot had 450 combat hours and 600 total hours in a CH-46 and listed scratches as the number one problem.

Ft. Rucker Alabama (UH-1)

"Plastic windshields are too susceptible to scratches and distortion."

Ft. Hood, Texas

"Help prevent scratches. Use a material that will prevent distortion at an angle."

Ft. Hood, Texas (UH-1)

"Windshield wipers cannot be used. Windshields are very critical in marginal weather and our division is an all-weather division."

Santa Ana Air Station (CH-46)

"Wiper blade needs 6 to 8 psi of pressure to wipe properly - this scratches; reduce pressure, and wiper flaps."

There were many other reports and quotations listed in the questionnaires. The above comments and similar ones were made in relation to plastic windshields used on the CH-46, CH-53, and UH-1. For helicopters such as UH-2 and SH-3 that incorporate glass windshields, the quotations were exactly opposite. The following are samples.

Imperial Beach, California (SH-3)

"The windshields are great! No difficulties with main cockpit windshield."

Ft. Rucker, Alabama (CH-47)

"Recently while operating CH-47C aircraft with glass/glass windshield the scratching and delamination problem has been minimal."

It is believed that two other failure modes - distorted vision and mistreatment - are related to scratches of the main windshield. Some of the reports stated that running a wiper on the glass represented a mistreatment, since it scratched the plastic. Also, in some cases the distortion was reported to be a result of scratches. Thus, the severity of scratches would be of a somewhat larger magnitude if these two factors were taken into account.

Deice failure was another significant failure mode reported. It is possible that this mode is also underreported. At times, deice system failure is manifested by interlayer bubbling. This was not listed as a failure mode on the questionnaire and would probably account for additional emphasis if it were included. At the Marine Corps Air Station in Santa Ana, it is standard operating procedure to disconnect the heating system, since it is not required. It is also hardly ever used at Imperial Beach. The following is a quotation from a commander pilot: "I only turned the deice system on once and that was to help warm up the cockpit".

Question No. 2

While there were no suggested failure modes listed for Question No. 2, the typical answer was scratches and breaking: 38 percent reported scratches and 42 percent reported breakage.

While scratches were listed as a problem for side windows, the condition is allowed to exist in an advanced state without removal and replacement. The primary functions of the majority of these windows are to provide daylight and transparency, and they can perform these functions with an advanced stage of scratching. At the Marine Corps Air Station in Santa Ana, a panel is removed if "the depth of scratch is 10 percent of the thickness".

The bigger problem associated with side windows is breaking and blowing out. The body of a CH-53 reportedly flexes a substantial amount, and this causes the cabin windows to pop out. Another cause is aerodynamic pressure on greenhouse windows on takeoff, which was reported a number of times on the UH-2. There are also cases where personnel have put a foot through the top windows while working on the engine or related parts which require standing on the helicopter. Such could result in personnel injury. This points to the fact that the nonwindshield transparencies are not rigid enough and should be built to take aerodynamic as well as static loads.

Question No. 3

The answer to this question was varied, since "safety of flight" can be interpreted many different ways. However, one person reported eight to ten cases where the windshield imploded on an H-3. This was not fully understood, since it was reported to be related to the anti-ice system where the window "imploded" after the heat was turned on. One explanation could be glass breakage due to overheating or electrical shorting.

There were three reported bird strikes. However, it was not stated whether the bird penetrated the windshield.

One serious problem concerning flight safety appears to be reflections from instrument lights at night. The following is a quotation from Major Pilot at Santa Ana:

"Due to reflections of light from longitudinal stick indicator on windshield, I ripped it out while going aboard an LPH."

A second-hand report was also obtained where a pilot "crashed as a result of windshield reflections".

Question No. 4

There was a general reaction that the geographical location affects the performance of helicopter transparencies by 62 percent of the persons answering the questions. The most common answers were related to scratches and deicing. While most of the individuals were in climates where anti-ice equipment would not be used much, they had experience in cold climates and reported many problems such as overheating and electrical failure. Some examples related east coast to west coast experience, particularly personnel at the Marine Air Station in Santa Ana who were previously stationed at the Marine Air Station in Cherry Point, North Carolina.

Another critical factor is dust and dirt as experienced in Southeast Asia. The worst condition would be dusty atmospheres with occasional rain which would require windshield wipers. It was felt that conditions such as these promote scratching and shorten the life of the windshield.

Question No. 5

Sixty-four percent of the persons answered "Yes" to the need for deicing and twenty-four percent answered "No". The remainder either did not answer or were vague.

Most of the remarks can be summarized by the following which are excerpts from an interview with a Colonel, Chief of Aviation Division, ODCS, U. S. Army in Heidelberg, Germany:

Question: Are you familiar with the glass windshields flown in Germany on the UH-1?

Answer: No.

Question: The German Air Force put glass windshields in three different UH-1 helicopters and are to fly them in different climates in Germany.

Answer: All I know is what I've been told which isn't nearly enough.

Question: Well, we have not received any report to my knowledge, but PPG has done the same thing at one of the military bases in Alabama and

Answer: Well, you see that is what I consider to be half of my damn problem. We are doing for the whole world what happens in Alabama, specifically, Ft. Rucker; and this is what we're paying for over here now.

Question: What is that?

Answer: Ice up in Fort Rucker. There is no great requirement there and there sure is here, and you only have to look at what big brother is doing with his helicopter to know what is required to fly in this condition, all weather, around the clock, year round.

Question: Are they flying deiced windshields?

Answer: You bet they are. They are hot from the time the engine starts until they shut down.

Question: You feel than that deicing is a must?

Answer: There would be a problem unless measures are taken in the form of heating or deicing.

Thus, the general feeling was that only by providing deicing capability can all-weather performance be obtained.

Question No. 6

The answer to this question closely paralleled the answers to No. 1. Sixty percent felt that scratches were lived with and 34 percent felt that deicing problems were lived with. A small number, eight percent, cited breakage. It appears as though such problems have been around so long and are so universal that maintenance people and pilots take them for granted and live with them. They do receive some attention, however. The

following was taken from a "CH 46 Fleet Modernization Program" written in March 1971 by a Major at the Marine Corps Air Station in Santa Ana, California, where he outlined the problems encountered with the CH-46 and recommended solutions:

1. Provide anti-iced glass windshield which will be scratch resistant.
2. Provide better night flight capability by eliminating reflections from instrument lights.
3. Reduce spares and maintenance manhours requirements.

GENERAL

Although it cannot be considered a failure mode, a number of problems were cited concerning windshield replacement. The parts on a CH-46 are bedded with Products Research and Chemical Corp. material PR-1422 per MIL-S-8802D. This material hardens after exposure to the natural elements and through normal cure. This not only makes removal difficult, it also results in a shearing of bolt heads since the bedding compound "welds the bolts in". In order to combat this, maintenance personnel at Santa Ana recommended round heat bolts to replace flat head bolts since the former have more mass. A typical comment was "two or three sheared bolt heads can make a window replacement a full-time job".

By contrast, UH-2 windshields are bedded with a zinc-chromate tape which requires no cure and remains flexible in time. The problems reported with this installation were minimal and resulted in relatively short replacement times. No indications of rain erosion have been reported.

Still another problem was reported with windshield and window cleaning at Imperial Beach. The material used is "Cleaning and Polishing Compound Plastic Type I (790-634-5340)". The solution requires applying and drying before removing. With the humid atmosphere at San Diego, the cleaning agent is removed before it is completely dry, and this results in streaks that are particularly objectionable at night.

SUMMARY OF QUESTIONNAIRES

The following sample questionnaire summarizes the answers received and the comments made:

1. How would you rank different failure modes of main cockpit windshields in order of decreasing frequency?

<u>Most Frequent</u>	<u>Percentage</u>
Scratches	61
Cracking and Breaking	2
Deice Failure	4
Cleaning Problems	4
Attack of Solvents	0
Distorted Vision	10
Mistreatment	8

2. What are the two most common failure modes of windows other than main cockpit windshields?

1) Scratches - 38%

2) Breakage - 42%

3. Do you know of a particular case where a windshield or window failure has affected the safety of the flight?

1) Windshield Implosion

2) Bird Strikes

3) Reflections

4. Is there any indication that a certain type of mission or geographical location experiences a higher windshield usage rate?

1) Deice System in Cold Weather

2) Windshield Scratches in Dusty Atmosphere with Rain

5. Do you feel that helicopter windshields and windows should have de-icing capability?

Yes - 64%

No - 24%

Unanswered - 12%
or Vague

6. Which of the problems listed in Question No. 1 do you think are being "lived with" only because they have existed for such a long period of time, but definitely require a solution?

Scratches - 60%

Deice - 34%

Breakage - 8%

FAILURE MODE DESCRIPTION

The following sections describe and discuss the various failure modes that were discovered by examining numerous helicopters and helicopter transparencies in service. For the most part, photographs are included to demonstrate the failure mode. At times, poor conditions yielded less-descriptive photographs. Where applicable, detailed failure analysis reports are also presented in order to establish the cause of failure. This is certainly necessary for the suggestion of remedial action.

Reflections

As stated in previous sections reflections from windshields at night have been of sufficient severity to cause a crash in one instance. It is not possible to completely eliminate reflections from the surfaces of any type of transparency since they are obtained from every smooth interface of materials with different indices of refraction. The outboard and inboard surfaces will always be reflective and a third reflective surface may result from the electrical conductive film in heated laminates. Polished glass surfaces reflect approximately 4 percent of the incident light whereas plastic surfaces are slightly less reflective. Multiple images, separated reflections from the inboard and outboard surfaces, may occur when the incident light is reflected at small angles to the windshield surfaces. The separation of the images is influenced by the thickness, the degree of wedginess, the curvature of the windshield and the incident angle. The thicker the actual transparency the more the reflections tend to separate. Figure 11 shows multiple reflections.

The only method now available for combating multiple reflections is to reduce the reflections by addition of an antireflection coating which has low reflection characteristics. Addition of this coating to a surface reduces the normally reflected light from that surface by 50 percent, but its efficiency is drastically reduced at high angles of incidence.

Current coatings are not sufficiently durable to withstand normal cleaning. The state of the art is such that these coatings are more durable on glass substrate than they are on plastics.

Another method of solving windshield reflection problems is by appropriate cockpit and instrument lighting design.

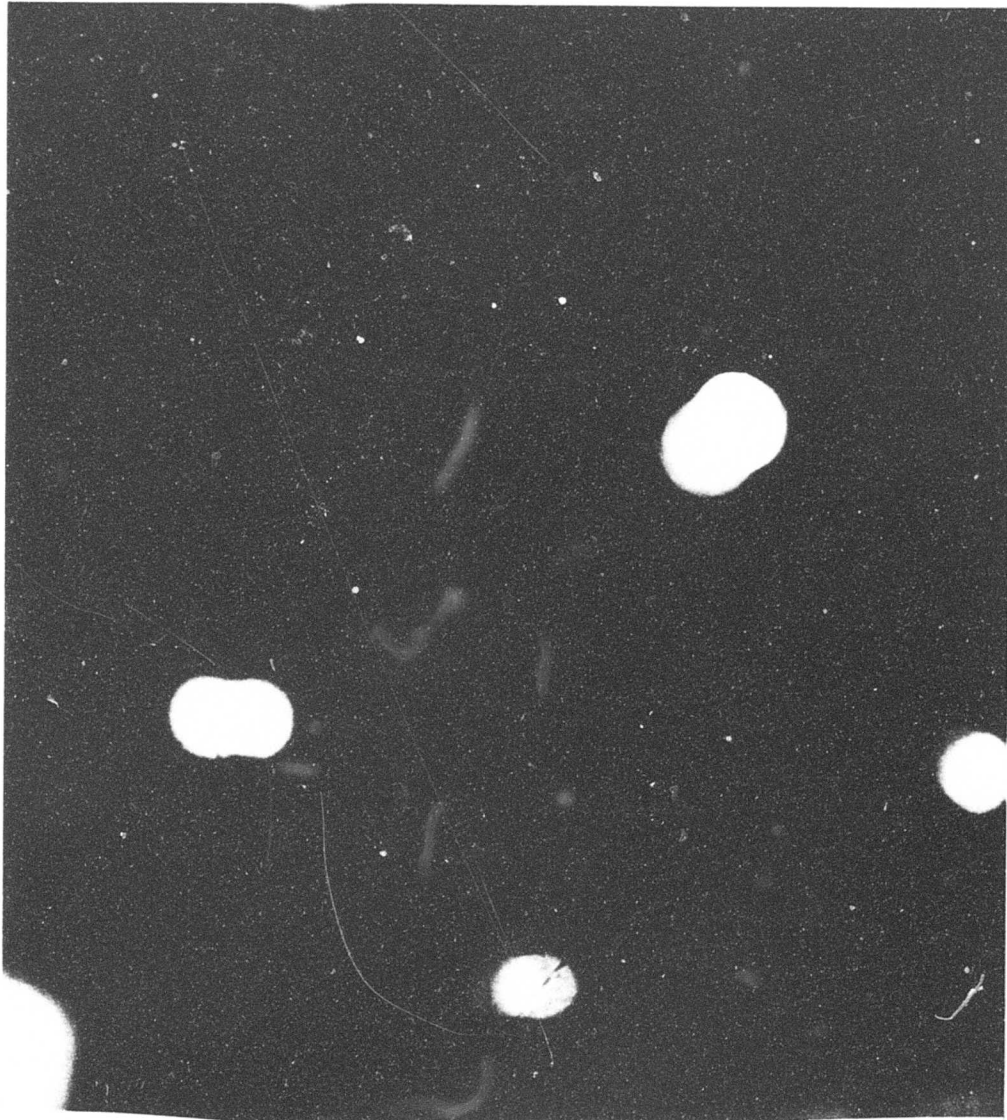


Figure 11. Double images (multiple reflections
Off Two Surfaces), OH-58.

Distortion

Distortion has been tabulated as a failure mode of various helicopter transparencies and is normally related to scratching, delamination, or structural rigidity. Distortion itself is not a failure mode that is affected by window life or usage, but an effect caused by another type of failure mode. In some cases distortion may become more objectionable than the original mode that caused it.

No attempt will be made to discuss basic physical reasons for distortion in transparent enclosures caused by fabricating processes since the optical quality of windshields as received by the user is satisfactory. Hence, this discussion will be limited to service causes that effect the optics of transparencies.

Scratching (and particularly attempts to polish scratches out) is one way that a window can become optically objectionable. A UH-1 was examined at Fort Rucker where windshield-wiper abrasion occurred to a degree in the acrylic that distortion in the scratched area was becoming as objectionable as the scratches themselves. The scratches did not appear deep, but it is suspected that attempts were made to polish the scratches out which tended to smooth out and widen the scratch. When accomplished properly, repair of light scratches does not degrade the optical quality. However, polishing of heavy or numerous scratches can cause surface imperfections that distort vision. Figure 12 illustrates this for a windshield.

Distortion effects around delaminated areas of main windshields are caused by the nonparallelism of the inner and outer surfaces of the windows; the delaminated area is thicker than the nondelaminated area. This type of failure would be typical in windshields where the delaminated area would be in a noncritical area around the edge of the windshield and acceptable, but the distortion effects would extend into the critical viewing area of the windshield, thereby causing replacement of the windshield. Figure 13 shows distortion associated with delamination of a windshield.

Side windows and door windows constructed of very thin monolithic plastic have a tendency to deflect and vibrate in flight, thereby giving a distorted image. The movement and vibration of the window would magnify the optical defects and cause the image to move abruptly. A thicker and more rigid window would reduce deflections and vibrations and provide a more constant viewing area.

Scratches

Scratches on the surface represent the most common and widespread defect found. By far the most common cause was from windshield-wipers used on plastic-faced parts. Figure 14 shows wiper scratches on the UH-1. Similar damage was much less common on glass surfaces and were generally



**Figure 12. Distortion Due To Repaired Scratches
on Plastic Windshield.**

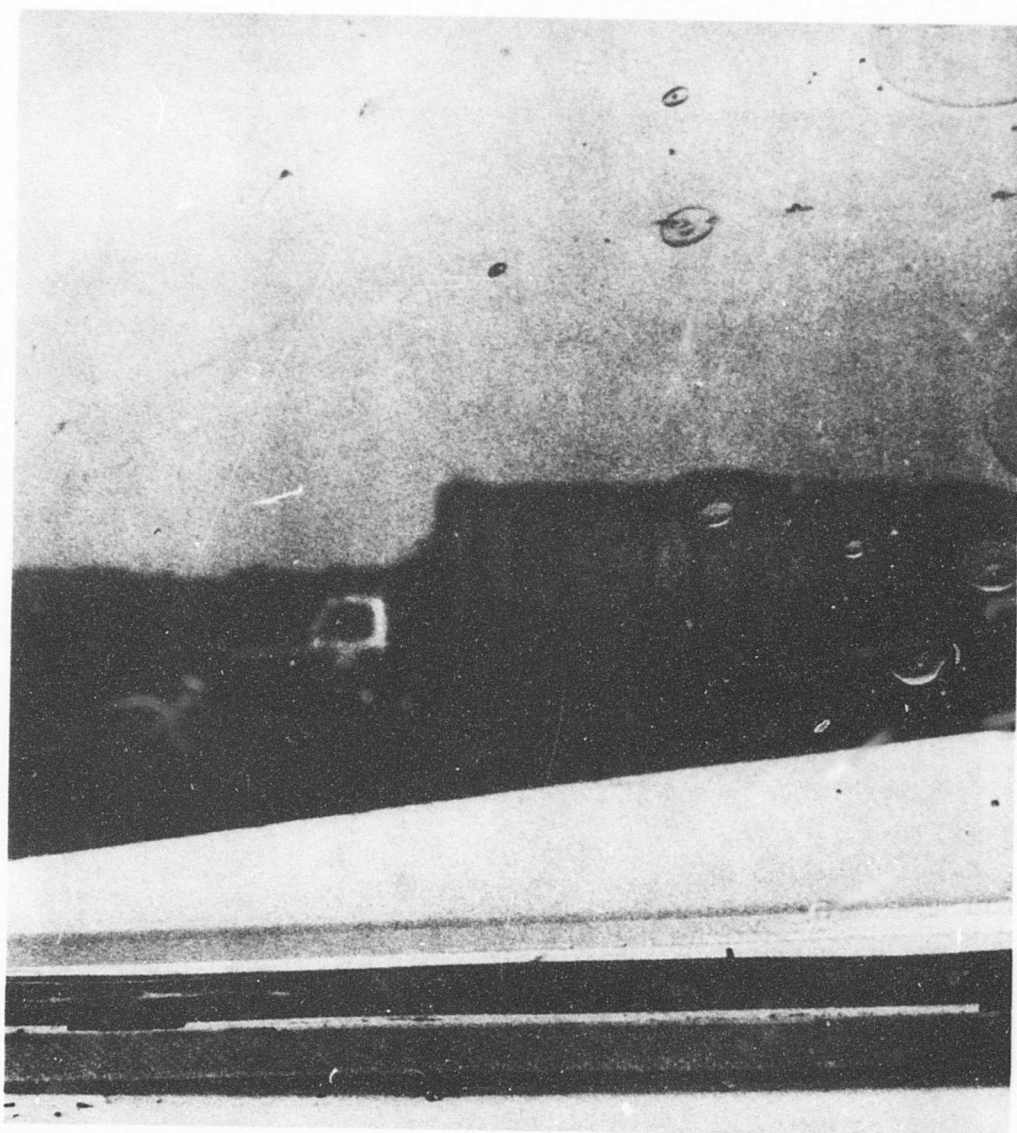


Figure 13. Distortion Caused by Delamination
of Plastic Windshield, CH-46.



Figure 14. Wiper Scratches on Plastic Windshield, UH-1.

limited to sleaks and light scratches. The second most common cause was abrasive particles captured in the downward airflow produced by the rotors that subsequently struck the plastic surfaces.

A highly touted scratch repair method was presented at Fort Rucker which involved the use of a scratch removal kit for plastic transparencies (FSN 1560-450-3622). Panels viewed that had been repaired with the kit removed scratches but left various degrees of distortion in the area of the repair. In some instances the distortion would not be objectionable in flight. However, other cases of excessive polishing did cause obvious degradation. Figure 15 shows a CH-53 side window with scratches and overall degrading.

Replacement of scratched plastic windshields with glass-faced windshields on the CH-47 helicopter at Fort Rucker called for the replacement of the wiper blade assembly at the same time. The new assembly (FSN 1680-133-7219) has a harder rubber blade and is restricted to use on glass windshields only. No problems with scratching from wiper operation have been reported.

Cracking

Cracking of monolithic plastic windows can be induced by mistreatment or impact, stresses induced from installation or airframe racking, and improper drilling and machining techniques. Suitable repair procedures are given in the applicable Technical Manuals which describe areas of the windows in which cracks can be tolerated and recommended kits for repair. Interviews with maintenance people at Fort Rucker indicate that the type of window installation (rivet or screw) dictated whether a cracked transparency would be repaired or replaced. If a repair could be accomplished in less time than the window could be replaced, it was usually repaired. Cracking of glass-faced heated windshields can be induced by the same cause as stated above, or also by a heating film failure where a high gradient hot-spot would create thermal stresses and cause glass breakage. A photograph of a cracked plastic CH-47 copilot windshield (Figure 16) and a cracked glass CH-47 pilot's windshield (Figure 17) are included for inspection.

Crazing

Crazing of acrylic and polycarbonate can be described as minute cracks in the surface of the material. Whereas scratches are directional and tend to be longitudinal, crazing is more of a network and branches of small fissures. While scratching is caused by mechanical action, crazing for the most part is caused by chemicals. Table 61 lists chemicals and their effect on various plastics.

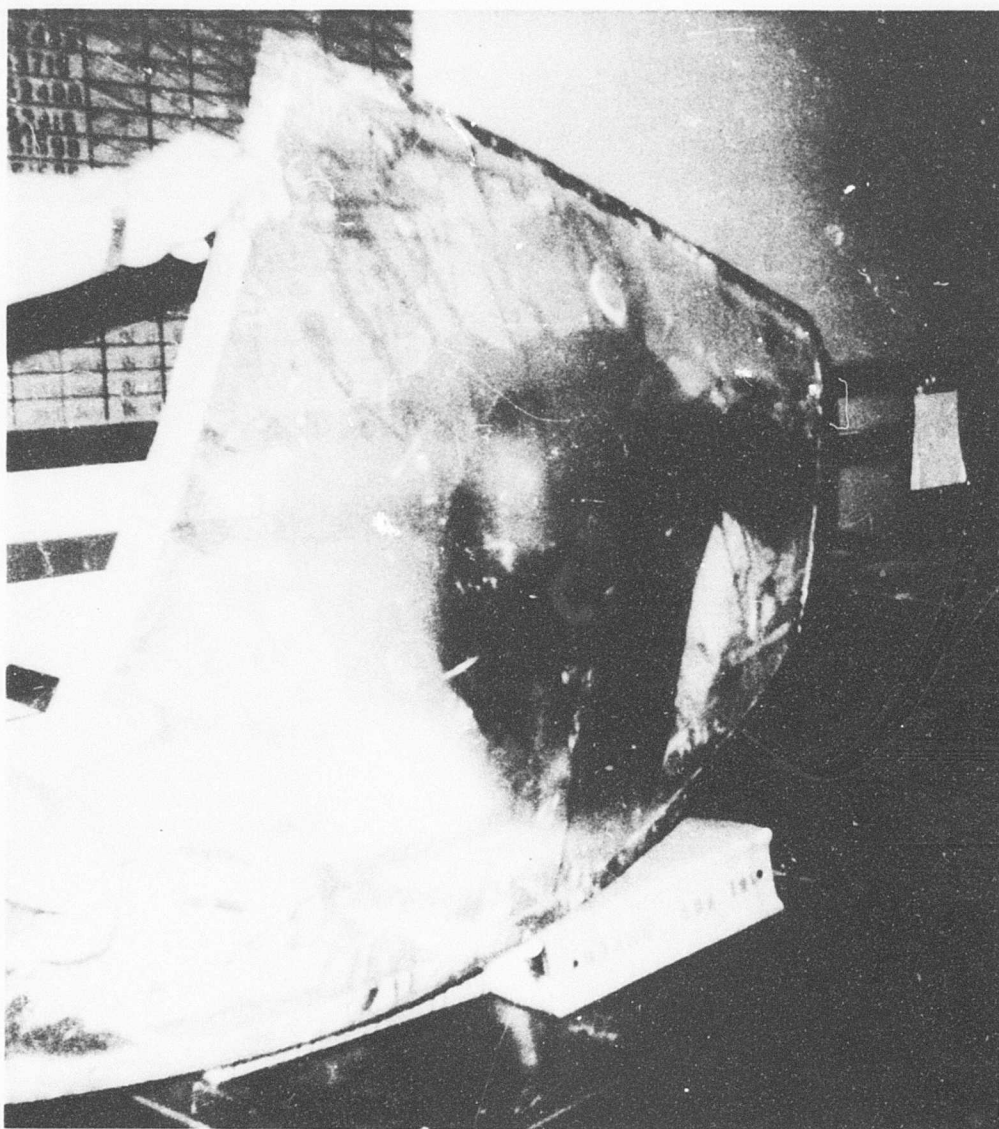


Figure 15. CH-53 Side Window Showing Scratches and Overall Degrading.

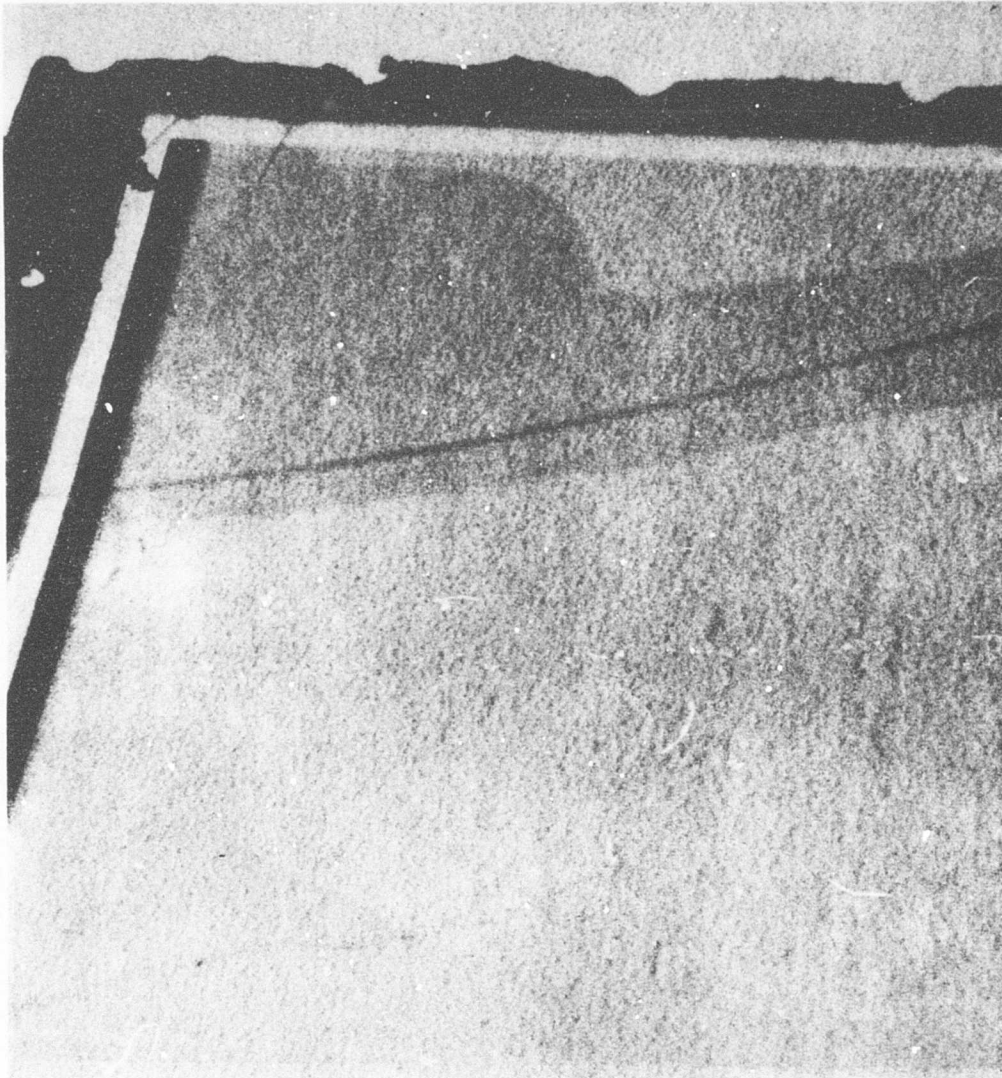
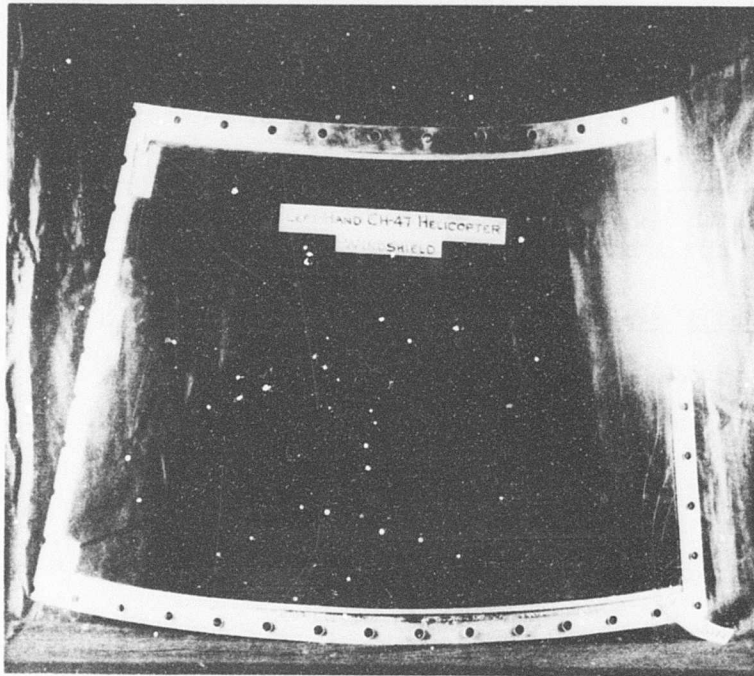
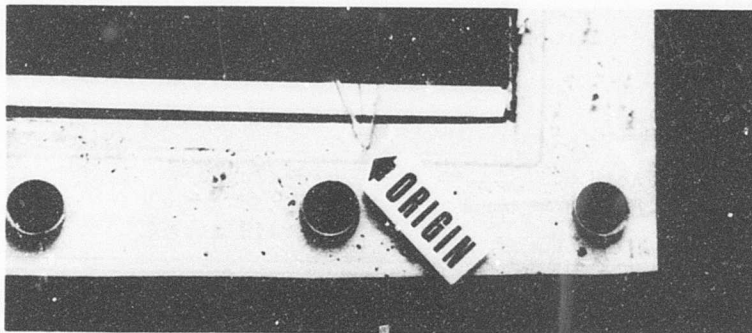


Figure 16. Crack in Plastic Windshield, CH-47.



Overall Outside View Showing Break Pattern



Close-up of Fracture Origin Located at Edge Seam on Outside Surface

Figure 17. Breakage of Glass Windshield, CH-47.

The magnitude of crazing is influenced by the amount of stress in the part. In other words, if a plastic part is loaded in tension and then exposed to a solvent which initiates minute cracks, the stress propagates the cracks to an advanced stage. Thus, they become more visible and the fissures tend to be directed perpendicular to the stress. At this stage the crazing resembles light scratches.

TABLE 61. CHEMICALS WHICH ATTACK GLAZING MATERIALS

<u>Acrylic</u> <u>Stretched MIL-P-25690A, As-Cast MIL-P-8184</u>	
Strong Acids	Attack
Aromatic Hydrocarbons	Resists Some
Esters	Attack
Alcohols	Resists Some
Chlorinated Hydrocarbons	Some Attack
 <u>Polycarbonate 9030 Color 112</u>	
Strong Acids	Attack Slowly
Weak Alkalies	Limited Resistance
Strong Alkalies	Attack
Alcohols	Resists Some
Esters	Attack
Ketones	Attack
Aromatic Hydrocarbons	Soluble
Chlorinated Hydrocarbons	Soluble
 <u>Glass (Soda Lime)</u>	
Hydrofluoride Acid	Soluble
Concentrated H_3PO_4	Mild Attack
Alkali	Mild Attack

Figure 18 shows a sample of reported crazing of the acrylic windshield of an OH-6 helicopter. The condition shown will result in an intense objectionable glare in daylight or night operation.

Bird Impact

The impact of birds with all types of aircraft is a problem of one degree or another. Part 25 of the Federal Aviation Administration Regulations states that windshields directly in front of the pilots must withstand,

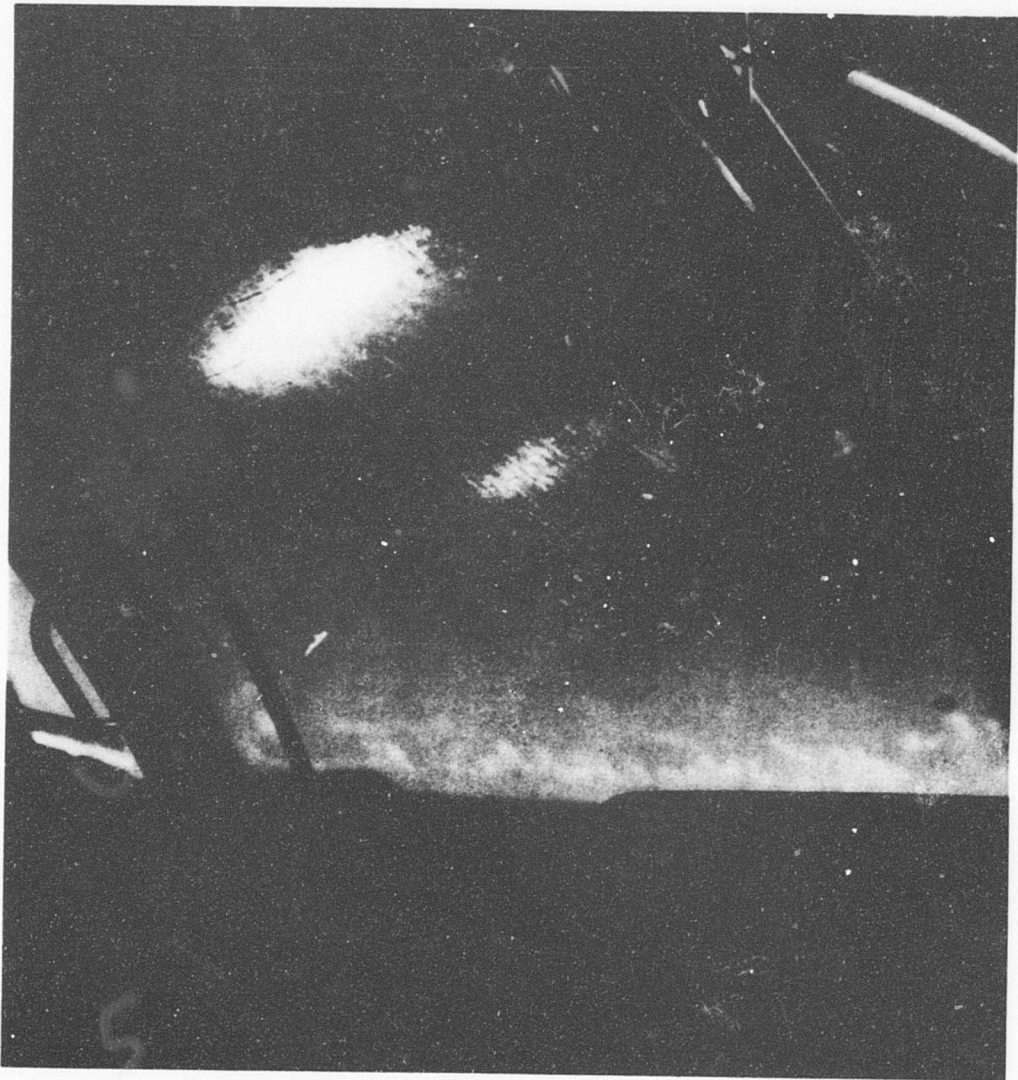


Figure 18. Crazing on Plastic Windshield, OH-6.

without penetration, the impact of a 4-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to the cruise velocity at sea level. This governs the design of commercial aviation windshields and is part of the qualification testing for these parts.

Until recently there has been no restriction on general type aircraft in this country. However, Part 23 of the FAA Regulations now imposes a bird-impact restriction on aircraft carrying nine or more passengers, and the same testing as for commercial airplane parts will now be required on new designs.

In the past, military aircraft, including helicopters, have not been subject to bird-impact requirements. Recent experience, however, has shown that bird strikes can be experienced, particularly on aircraft that fly at relatively low altitudes such as the F-111. Based on this experience, the Air Force is requiring a bird-strike capability for the windshields on the B-1 bomber. They have also issued a study contract on the subject to gain more knowledge on material capability in order to provide guidance for future windshield design.

There has never been a bird-impact requirement on any of the helicopter windshields in service. Nevertheless, a limited amount of testing was accomplished on the center glass windshield of the PPG Industries design for the CH-53. The windshield was mounted in a test frame set at an angle of 45° from the line of flight of the impacting bird. In cross section, the windshield is two pieces of .100-in. semitempered glass laminated with .060-in.-thick PVB interlayer.

Figure 19 shows the result of a 1-pound bird impacted at the center of the panel at a speed of 101 kt (116 mph). Both plies of glass shattered, but there was no bird penetration past the windshield. Residual vision would be very poor through the windshield after such a strike, and landing would have to be accomplished from the side or copilot windshield. Subsequent strikes were also made at 150 kt (173 mph) with a 1-pound bird and 89 kt (102 mph) with a 4-pound bird. No penetration was obtained with the former, but the 4-pound bird did penetrate.

The mode of failure under bird-impact loading is such that the basic tensile strength of the glass is overcome. The loading is so rapid that the interlayer yields very little and the two pieces of glass instantaneously act as a solid. Once the glass fractures, energy absorption is taken over by the interlayer. If this member is sufficiently thick, it will "bag" the bird and prohibit penetration. If not, the interlayer tears and the bird penetrates into the cockpit.

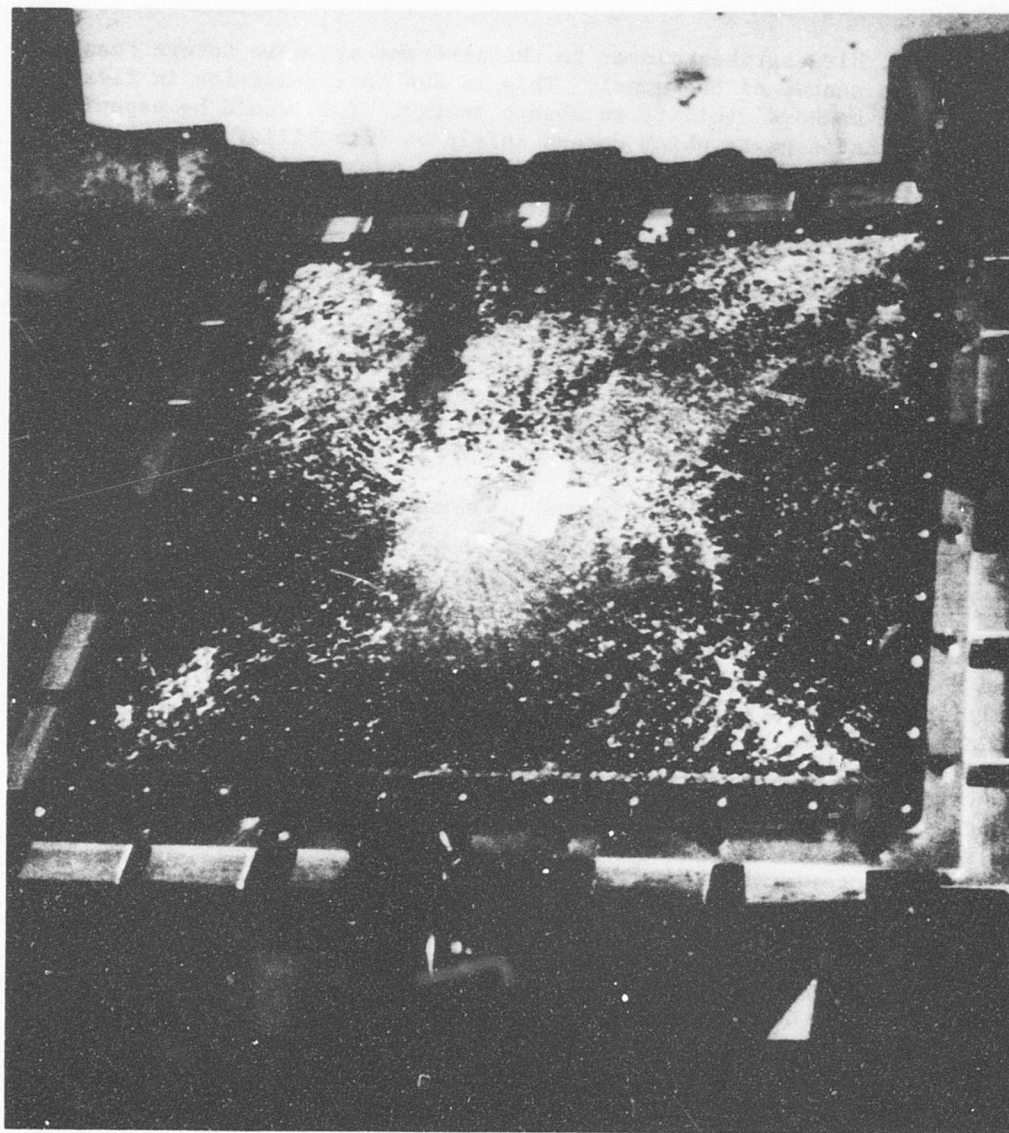


Figure 19. Bird Shot Damage of Center Windshield,
CH-53.

In general, bird strikes closer to the airframe are more severe than those made at the center of the panel. This is due to a reduction in flexibility and the members' ability to absorb energy. This would be especially true for plastic parts which depend solely on flexibility to withstand impact. Hence, a transparency of sufficient mass or thickness to bounce a bird could be superior to a plastic panel for this type of impact.

Another factor affecting impact strength is temperature. As the ambient temperature is reduced, materials such as acrylic, polycarbonate, and PVB in a glass laminate become less resilient and incapable of absorbing large amounts of energy. Depending on thickness and processing variables, acrylic and PVB used in glass laminates show loss of resilience at room temperature, whereas for polycarbonate, the threshold temperature is about 65°F below zero. Thus, it becomes very important to select a temperature at which protection against birds is to be provided.

Although bird strikes were reported in service, the panels were not available for inspection.

Ballistics

With the exception of the lower forward quarter panels on some models of the H-3 helicopter, no other helicopter transparencies are designed to be ballistic resistant. Even though a ballistic failure is not always related to window life, some discussion is of merit for typical helicopter glazing materials. Extractions from a Department of the Army report concerning testing of CH-47 windshields follow. In summary, the report concludes that both glass and plastic materials presently used are suitable materials in that vision through the windshield is maintained and the spall characteristics are acceptable.⁶

"1. Two prototype windshields that are proposed for use in the CH-47C aircraft were received by these Laboratories for ballistic examination. The ballistic test was to be one of a number of tests conducted on these prototypes; the results of these tests to be used as a basis for determining the desirability of either type for replacement of the currently installed windshield.

2. One of the windshields was designated as PPG glass P/N VER-18-008-1 and the other was designated as Sierracin Corporation P/N 3-132500-2.

3. The test plan which had been designed by the Boeing-Vertol Company for Contract DDAAJ01-68-C1566(M) specified that the ballistic test was to use 7.62mm ammunition impacting at a 63 degree obliquity. The Soviet 7.62 x 39mm BALL projectile was chosen as a representative munition and was fired at service velocity.

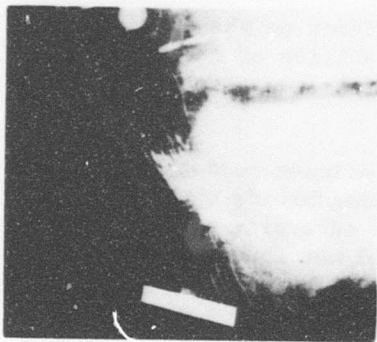
4. A total of two impacts were obtained on each windshield. A sheet of 0.08-inch thick plexiglas was positioned behind the windshield to note the spallation and its effect on the plexiglas. This would provide a measure of the ability of the visor in an aviator's helmet to prevent wounding from glass spallation.

5. In general the results of the firings indicate no noticeable difference in the performance of the windshields when subjected to 7.62mm impact. Just about the same size hole was noted and cracking of the windshield did not appear to be different with regard to reduced visibility. There is a likelihood, however, of increased cracking if the windshields were subjected to the normal stress and strain produced by the twists and turns of normal flight, but the magnitude of this increased cracking cannot be ascertained from these tests. Figure 20, which is enclosed, shows the extent of the cracking in each windshield after each impact. Figure 21, also enclosed, illustrates two things; the general target arrangement showing the mounting of the windshield and the recovery box located aft of the windshield; the damage done to the plexiglas witness sheets. The significant thing to note on the plexiglas is the lack of any perforations away from the immediate area of the bullet trajectory. The large holes in the plexiglas were caused by the bullet itself. The spallation that resulted from the impact did not penetrate the plexiglas sheet indicating that the visor in the aviation helmet would provide protection from this type of spall.

6. From a ballistic viewpoint there is no basis for preferring one construction over the other as either is satisfactory."

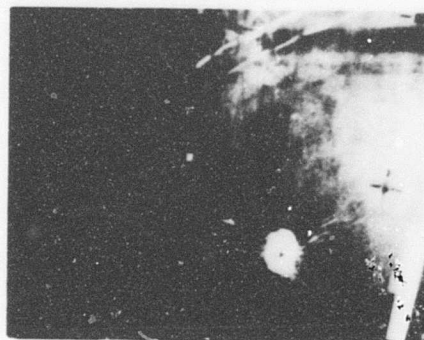
Structural Rigidity of Glazing Materials

Although not a recognized mode of failure, interviews with maintenance personnel at Fort Rucker and Naval Air Systems Command indicate that some existing window panels do not have required structural rigidity. Inspection of an OH-6 helicopter at Fort Rucker revealed that some of the upper transparent areas and door windows were taped to the airframe structure. A Captain at Fort Rucker indicated they were taped in place because they had come loose from the framing members during previous flights. Figure 22 illustrates a cockpit window held in place with tape on an OH-6 helicopter. Also an interview with a representative of New York Airways told of an upper observation window on a S-61 popping out and being ingested into the engine air intake causing emergency action to be taken. The following excerpts are from an official Navy report which gives instances of windows coming loose during flight operations.

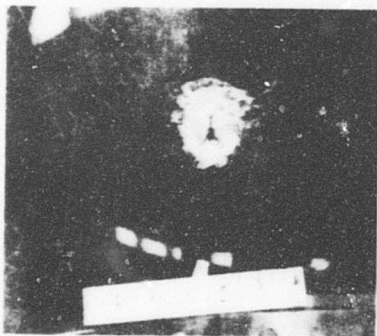


PPG Construction

First
Impact



Sierracin Construction



Second
Impact

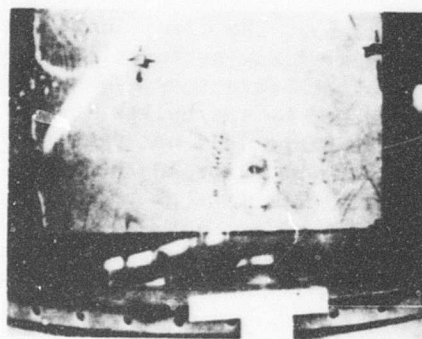
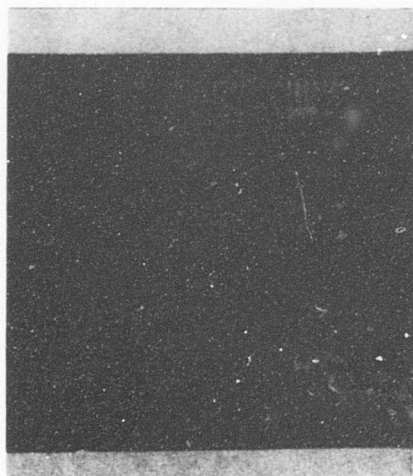


Figure 20. Ballistic Tests of CH-47 Windshields
Soviet 7.62 X 39 mm Ball Ammo.



Typical Plexiglas Results



Target Arrangement



Figure 21. Ballistic Tests
Arrangement and
Plexiglas Results.



Figure 22. Outside View of OH-6 Windshield
Showing Taping to Airframe.

"A summary of Navy/Marine helicopter safety URS for the preceding sixty days indicates that seventeen instances of door window or inspection panel distress occurred during flight operations. The following were reported:

HH-2D	STBD Cabin Door, Lost in Flight
SH-3H	Co Pilots Window, Lost in Flight
CH-53D	Cabin Window, Lost in Flight
CH-53D	Fwd Cabin Escape Hatch Window, Lost in Flight
CH-53A	Cabin Side Window, Lost in Flight
CH-53A	Pilots Window, Lost in Flight

Analysis reveals that all present model Navy/Marine helicopters suffer from door, window, and panel malfunctions or losses and are preventable.

By separate msg, NAVAIRSYSCOMHQ has been requested to initiate action to improve material reliability of the above mentioned items for existing and future helicopter designs."

Delamination

The loss of adhesion between the interlayer and glass or acrylic ply is shown in Figure 23. This can result from continued exposure to high humidity. Glass faced laminated to acrylic parts are more prone toward delamination than glass/PVB/glass parts. Laboratory tests of composite glass acrylic parts, have shown interlayer degradation attributed to moisture penetration through the acrylic. Since glass is impervious to moisture, similar tests showed no bond deterioration.

Water vapor entrance through the edge of laminated parts must be prevented by the use of bumper strips and edge sealants. Sealant deterioration and/or improper application especially on replacement installations can permit attack that leads to delamination.

Differences in the coefficient of thermal expansion of materials in a laminate affect delamination. The coefficient of thermal expansion of the normal interlayer material (PVB) is approximately ten times that of glass. As a laminate of glass/PVB/glass experiences gross temperature changes, extremely high shear forces parallel to the surface exist at the glass-PVB interface that contribute to adhesion failure. This is also true for glass/PVB/acrylic composites. However, additional bending stresses exist because of the unbalanced glass-acrylic configuration.



Figure 23. Severe Delamination of Plastic Windshield, CH-47.

Since the thermal expansion coefficient of acrylic approaches that of the interlayer the combined stresses can lead to early delamination in unbalanced composite structures.

Overheating

Overheating in an electrically heated windshield can be caused by:

1. Sensing element malfunction
2. Controller malfunction
3. Breakdown of the bus bar system
4. Interruption of the conductive film due to cracking of the substrate

Initial indications of overheating are associated with small bubbles in the interlayer material (as shown by Figure 24) or by a yellow or brown appearance in a localized area usually along the bus bar. This result of the latter condition is shown in Figure 25. With continued overheating these bubbles grow forming gross areas of delamination as shown by Figure 26. Any delamination adversely affects the optical quality, causing severe distortion. If bus bar failure or film interruption occurs, shorting and associated arcing may develop, causing the panel to fracture.

Glossary

A glossary of terms commonly used in the aircraft industry to describe transparent parts and related failure modes is included in the report. This glossary should be made available to personnel in the field to improve informational feedback to the supplier. An accurate description of a failure mode is certainly a prerequisite for a solution to the problem.

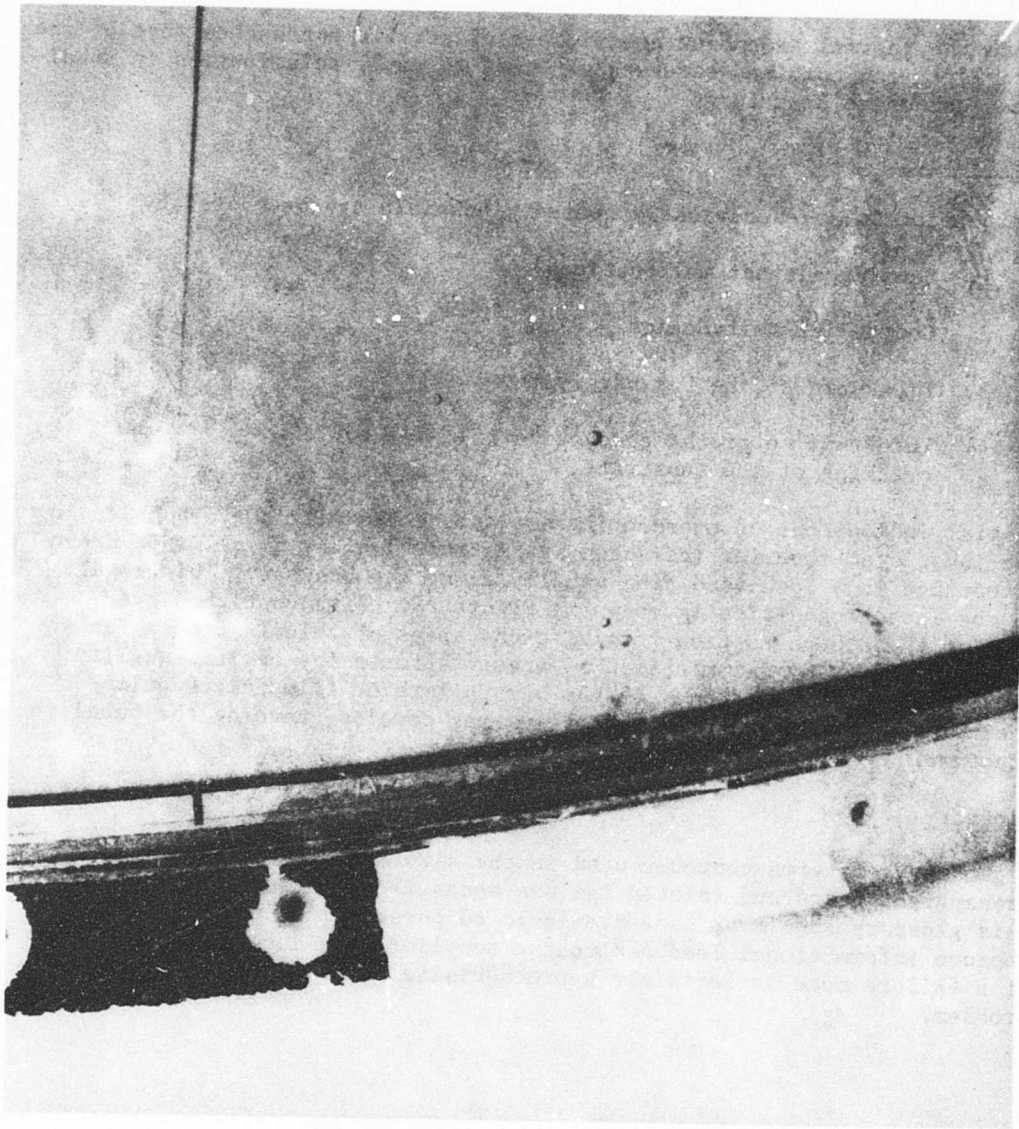


Figure 24. CH-53 Windshield Showing Bubbles
Caused by Overheating.

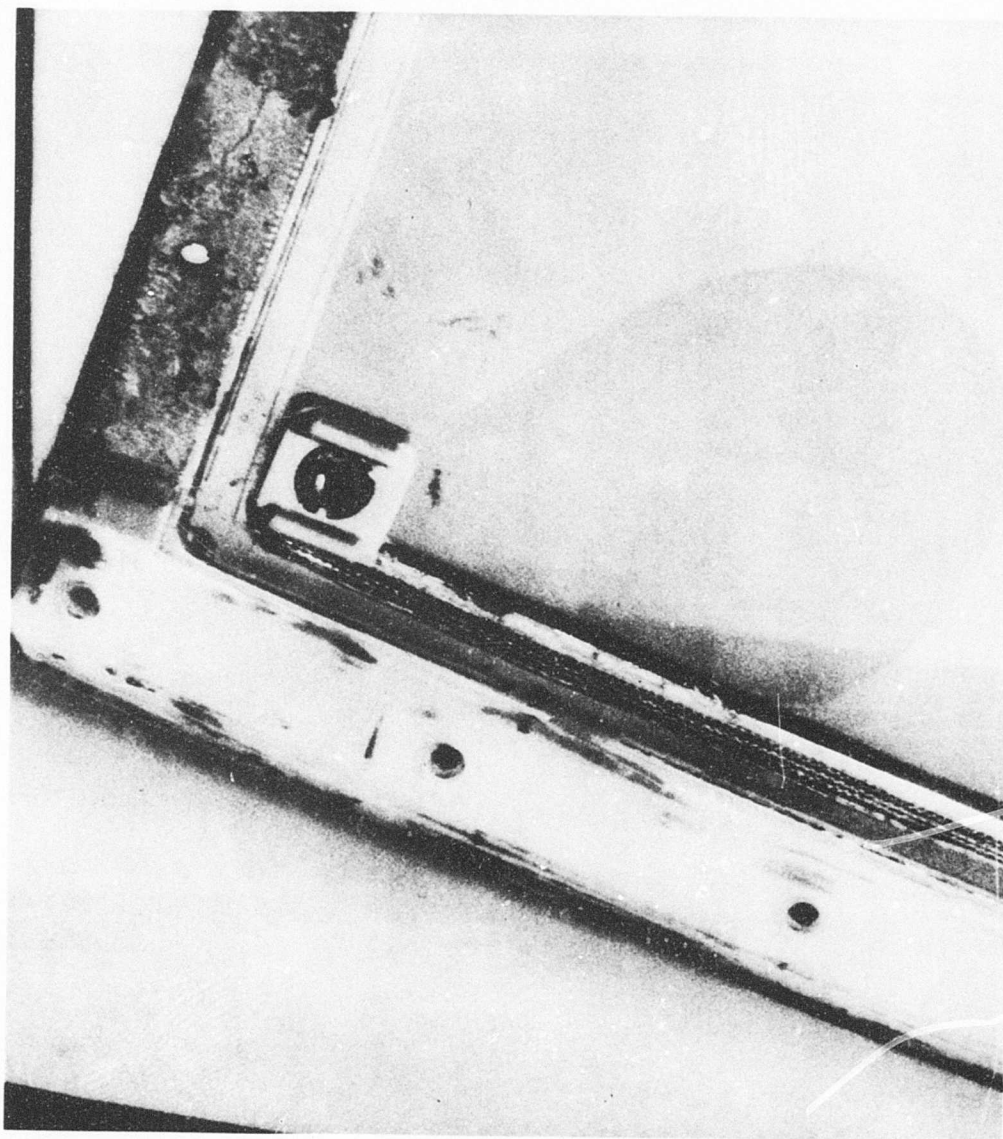


Figure 25. Bus Bar Failure Leading to Overheating and Delamination of Plastic Windshield, CH-53.

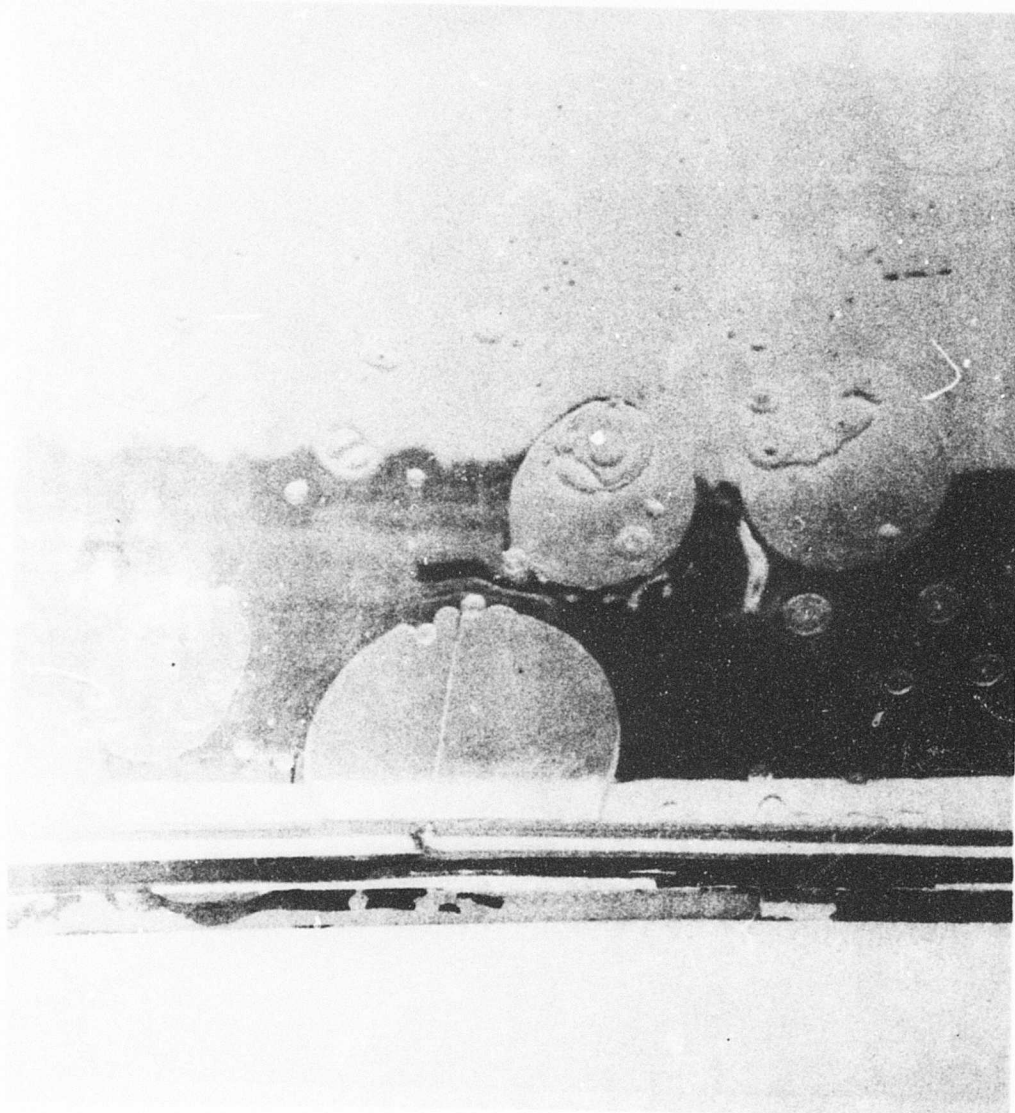


Figure 26. Bubbling Caused by Overheating
Progressing to Severe Delamination
on Plastic Windshield, CH-46.

APPENDIX IV

PREVENTIVE MAINTENANCE

An analysis of the appropriate information found in the following technical manuals and repair procedures was conducted.

1. General Aircraft Maintenance Manual, TM-55-1500-204-25/1 Army.
2. Organizational Maintenance Manual, TM-55-1520-210-20 - Army. Army Model UH-ID/H Helicopters, September 1971.
3. DS and GS Maintenance Manual, TM-55-1520-227-34-3 - Army. Army Model CH-47B and CH-47C helicopter, January 1972.
4. DS, GS and Depot Maintenance Manual, October 1970, TM-55-1520-228-35 - Army, OH-58Z helicopter.
5. Manual Maintenance Instructions - Air Frame NAVAIR 01-260HCA-2-2 - Navy, UH-2A/UH2B/UH-2C/HH-2C/HH-2D/5H-2D.
6. Scratch Removal for Plastic Transparent Surfaces, SS9577 Material - Process Specification, Sikorsky.
7. Fabrication, Storage and Handling of Transparent Enclosures for Stretched Acrylic Sheet. CE-2649 - Cessna Specification.

GENERAL

All the manuals and repair procedures addressed transparencies made of plastic-acrylic based materials. Therefore, the findings of this review are completely related to acrylic materials without any reference to glass. However, many of the preventive maintenance techniques that are lacking in the Government TM's are applicable to both materials, acrylic and glass.

From the review of the technical manuals (1-4), it is quite apparent that none of these manuals addressed preventive maintenance techniques. The manuals provided detailed information on installation of and repair of transparencies, with excellent coverage of

1. Transparent plug repair
2. Crack repair
3. Scratch polishing by hand and buffer
4. Patching
5. Overlay plastic/fabric patch repair

Missing, however, were standard preventive maintenance procedures such as

1. Material cleaning
2. Handling
3. Protection
4. Accessory usage (wipers)

Such procedures could minimize deterioration and prolong service life.

The Table of Contents and Subject Indexing of TM's 1-4 and TM 5 do not cover the subject of helicopter transparencies adequately enough to provide the user quick, easy access to pertinent sections covering transparency maintenance.

TM's 1-5 cover general information and repairs quite adequately and accurately. Precautions, safety measures, and warnings are highlighted adequately enough to caution those doing the work.

The manual published by Naval Air Systems Command (TM-5) covers both preventive maintenance topics as well as installation and repair procedures. Of the 5 service manuals reviewed, this one has the best presentation (total coverage), drawings, photographs, and overall content and effectiveness.

Process specifications (6 and 7) are not actual maintenance manuals but do cover the preventive maintenance topics such as acrylic handling, storage protection, etc., in detailed and effective fashion. Preventive maintenance topics in the Cessna and Sikorsky documents are well presented and complete. Information of this type could be used to fill the voids found in the Army manuals.

The two major shortcomings found in the review of the referenced TM's (preventive maintenance procedures and subject indexing) are addressed by the following recommendations.

PREVENTIVE MAINTENANCE PROCEDURES

Handling

1. To prevent damage to surfaces, handle all glazing materials (plastics, glass) carefully. Remove rings, wristwatches, and other hard objects from the hands. Also, remove or be careful of buttons, belt buckles, and tools (rules, pens, etc.) in pockets or on body that may come in contact with glazing material.

2. Handle glazing panels only at edges. Place glazing panels only on edges (never on surface) at a slight angle against a substantial support.
3. Avoid contact from other chemicals or cleaning materials for other aircraft parts from wet spill or harmful vapors (solvents, lacquer thinners, etc.).
4. Ventilate cabin interiors.

Cleaning

1. Never clean or wipe glazing surfaced dry; use soft wet cloth or sponge. Do not use hard, dirty, or gritty cleaning cloths or materials.
2. In case of hard soils or bugs, use mild soapy (MIL-D-16791) water with aid of bare hands and rinse with clean water. Final dry with light touch or with blotting using a slightly dampened soft cloth or chamois.
3. In case of stubborn soils on plastic surfaces, use soft cloth slightly dampened with aliphatic naphtha (TT-N-95 Naphtha Type II).
4. Never clean hot plastic surfaces in sunlight; cool by shading first.
5. In case of hazy surface condition, restore polished surface with appropriate polishing procedure and materials.
6. Clean interior surface to remove hazy film to restore optical clarity. Use mild cleaning conditions as above.

Inspection

1. Inspect windshields and windows for general condition (scratches, dents, cracks, holes, hazy film). Extent of condition determines whether temporary repair, major repair, minor polishing, or replacement is required.
2. Also, inspect windshields and windows for optical condition in noncritical or critical areas when usable or repairable.

Procedures (Daily or Frequent)

1. Clean transparencies from outboard soil conditions and inboard haze conditions.
2. Clean windshield wipers to dislodge soil or gritty particles on blades.

3. Give transparencies a cursory inspection for conditions that may be detrimental to successful flight mission. Handle appropriately with temporary repair or hold for permanent repair if required.

Procedures (Periodic)

1. Inspect and repair to restore surface quality and optical quality - polish brush marks, polish windshield wiper sweeps, remove scratches, correct digs, etc. (see TM).
2. Inspect and repair transparencies for defects (if feasible) of cracks, holes, crazing, etc. If not feasible, remove windshield or panel and install replacement.

Storage

1. If possible, cover transparencies with protective coverings of paper, cardboard, canvas, cloth, or plastic film to prevent accumulation of surface dust. More durable protective covers are necessary for longer storage periods.
2. Store replacement parts in a cool, dry condition with protective coverings.
3. Store replacement parts in cold arctic conditions with durable protective covers to prevent accumulation of snow and ice.
4. Store replacement parts in sandy, desert conditions with durable covers to prevent accumulation of sand and grit.
5. Store replacement parts on edge, preferably on two support rails, at a slight angle against a substantial support.

Installation (Replacement)

1. Remove defective part.
2. Inspect and repair frame.
3. Cover surface with protective cover and mask edges.
4. Install replacement.
5. Seal edges.
6. Remove protective covers.

Repair

1. Cover surface with protective cover and mask edges.
2. Determine type of repair (cracks, holes, surface scratches, digs, edge defects, etc.).
3. Repair (see TM procedures).
4. Repair edge seal.
5. Remove protective covers.

Windshield Wiper

1. Clean wiper blade from all dust and grit with soft, wet cloth. Lift blade only to wipe.
2. DO NOT RUN WIPER BLADE ON DRY WINDSHIELD SURFACE.
3. Check windshield wiping area for surface soil; clean according to procedures for transparencies.
4. Check conditions of windshield wiper rubber for resiliency and nicks. Replace as necessary.
5. Check operative condition of windshield wiping for sweep with blade in lifted position from surface. Adjust or repair as necessary.
6. Check tension of windshield wiper blade to surface. Adjust as necessary.

SUBJECT INDEXING

In an effort to resolve this, helicopter transparencies - windshields or windows (glass or plastic) - should be treated as subject entities and accordingly included in alphabetical index and table of contents with reference preferably to page numbers. These subject materials should be included in each set of manuals.

INTERVIEWS

As a supplement to this review of maintenance procedures, maintenance personnel were interviewed using the questionnaire illustrated in Figure 10 (Appendix III) at several bases (Fort Hood, Fort Rucker, Marine Corps Air Station, Sharpe Army Depot, Imperial Beach Naval Air Station). The questionnaires and interviews were conducted with a wide variety of military types (Major - Spec. 5) involving many different helicopters (UH-1, AH-1G, CH-47, HH-3, CH-53, OH-58, OH-6, CH-46).

Questionnaire

Five maintenance-type questions were asked. The questions and results follow:

1. Are prescribed methods for maintaining transparencies documented in technical manuals?

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Yes	46	93
No	3	7

2. If prescribed methods are available, are they used and adhered to?

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Yes	36	73
No	13	27

3. Are prescribed methods practical and easy in your opinion?

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Yes	41	83
No	8	17

4. What methods of your own(not prescribed) do you use to maintain transparencies?

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Other procedures	12	24
No procedures	24	48
No answer	13	28

5. What are the major problems associated with maintenance of transparencies in your opinion?

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Cleaning materials and equipment not available	11	22
Dust and dirt from rotor wash	5	10
Scratches and delamination	9	18

<u>Answer</u>	<u>No.</u>	<u>Percent</u>
Wipers cannot be used	6	12
No answer	10	20
Misc.	8	18

It is evident from review of these maintenance questions that most military personnel feel that maintenance procedures documented in the technical manuals are available, used, and accomplish the desired result. However, some of the comments obtained through personal interviews with maintenance and flight personnel tend to show the opposite.

Personal

Maintenance, Ft. Hood, Sgt., First Cavalry

Question: "Do the TM's contain adequate coverage for cleaning and repair of helicopter transparencies?"

Answer: "Repair techniques are adequate but cleaning techniques and procedures are practically non-existent and even if they existed, the materials for cleaning most likely would not be available. Cleaning and polishing compound plastic Type I 7930-634-5340 has not been available from supply since April, 1972."

Pilot, UH-1, Ft. Hood, Captain, First Cavalry

Question: "What preventive maintenance procedures do you use on helicopter transparencies?"

Answer: "The best preventive maintenance procedure I know of involves the windshield wipers. I personally never use the windshield wiper unless there is a dire emergency or a torrential downpour. In this way I don't scratch the windshield and my vision, especially at night flights, is not restricted."

In summation, preventive maintenance procedures in the TM's need to be expanded. Additional preventive maintenance procedures the TM's could dramatically help reduce transparency deterioration, prolong service life, and improve transparency quality.

APPENDIX V

BIRD STRIKE RESISTANCE

Since the late 1960's, a considerable number of bird strike tests have been conducted on designs for aircraft forward-facing transparencies (windshields). However, the vast majority of these tests at facilities in the United States, Canada, and England were designed to determine the bird resistant capability of transparencies used on general or high performance fixed-wing aircraft. Consequently, designs tested at velocities above 300 miles per hour (mph) were very heavy. Recent advances in process technology with subsequent availability of polycarbonate material with aircraft quality have reduced the weight of these bird resistant designs. Utilizing the impact strength of polycarbonate, designs are now fabricated that defeat the industry standard 4-pound bird at the speed of sound. However, such speeds are beyond the present realm of rotary-wing aircraft. Since overdesign of transparent structures is foolish, the bird strike capability of windshields in helicopters was studied with actual tests to determine the velocity limitations when impacted with a 4-pound bird.

DESIGNS

Table 62 shows the construction, number, and theoretical aerial density of the 26 in. x 26 in. samples prepared at PPG Industries for bird strike tests at the National Research Council, Ottawa, Canada.

TABLE 62. BIRD STRIKE TEST SAMPLES			
Design No.	Construction	Number of Samples	Aerial Density (lb pr sq ft)
I	1/4 In. Stretched Acrylic	4	1.54
II	1/4 In. Polycarbonate	6	1.56
III	.10 In. Glass-.10 In. PVB-.10 In. Glass	2	3.19
IV	.10 In. Glass-.10 In. Int.-.125 In. Polycarbonate	4	2.89
V	.10 In. Glass-.10 In. PVB-.10 In. Glass-.10 In. PVB-.10 In. Glass	3	5.07
VI	.10 In. Glass-.09 In. Int.-.125 In. Polycarbonate-.09 In. Int.-.10 In. Glass	2	4.52

Monolithics

Since the majority of the windshields in rotary-wing aircraft are acrylic, either stretched or as cast, it was considered important that acrylic be

tested, especially since bird strike failures have been reported for stretched acrylic windshields in the AH-1G. Therefore, 1/4 in. stretched acrylic was selected as a sample construction. Since it is fairly well accepted that acrylics, stretched and as cast, are comparable for impact capability, 1/4 in. polycarbonate was selected as the other monolithic material, in particular, since polycarbonate material has a high impact capability.

Glass Laminates

Previous tests as reported in Appendix III (Failure Mode Description, Bird Impact) indicated the conventional 2-ply glass design now used on aircraft such as the CH-47, 54 and UH-2 showed penetration when impacted with a 4-pound bird at 100 mph. Since 100 mph was the practical low velocity limit of the facility and changes to lower bird weights were not acceptable, some modifications were made in the glass laminate design. The initial sample size was reduced to two samples to substantiate previous results. Also, an additional glass ply was added to increase the bird resistance, thus arriving at the 3-ply glass design V.

Glass Plastic Laminates

Although the glass-polycarbonate composite design IV is not currently utilized in rotary-wing aircraft, it is considered to be a potential candidate with significant merit. On the surface, this unbalanced design resembles the glass-acrylic design currently used on the CH-46 and CH-47 aircraft. However, any similarity in actual bird resistant performance can only be possible if comparable results are obtained for the monolithic materials.

Two samples with polycarbonate buried within the interior of the panel were also selected to determine if glass on the inside would restrict the polycarbonate deflection, thus reducing its performance.

TRANSPARENT MATERIALS

Stretched Acrylic - Design I

The stretched acrylic was used as received with no processing necessary. The material was purchased from McDonnell-Douglas per MIL-P-25690.

Polycarbonate

All polycarbonate used in this program was General Electric Lexan aircraft grade SL-2000.

Design II, IV

After cutting the material to size, the polycarbonate was optically perfected by exposure to temperature and high pressure. The final exposed surfaces of all polycarbonate panels were covered with a protective hard coating, OI-650.

Design VI

The polycarbonate in this design was not optically perfected before lamination, and since the polycarbonate was buried, the OI-650 hard coating was not required.

Glass - Design III, IV, V, VI

The float glass was heat strengthened by a thermal tempering process. The processed glass thus had a partial temper of 700 millimicrons per inch as determined by center tension measurements.

Interlayer

All interlayers utilized in the test samples were of the sheet variety.

Design III, V

The interlayer utilized was the conventional aircraft grade polyvinyl butyral.

Design IV, VI

This interlayer was a special PPG material that is considered proprietary.

FABRICATION

All laminated assemblies were bonded by exposure to appropriate temperature and pressure. Since holes cannot be drilled in glass, inserts or edge reinforcements were utilized on all laminated assemblies whereas monolithic plastic panels were drilled without any reinforcement. Using a drill jig and backup plate, holes 5/16 in. in diameter were drilled around the periphery at 2 in. centers and 1/2 in. from the edge. After an inspection, the panels were transported to Ottawa for testing.

TEST SETUP

Each panel to be tested was supported with 1-in.-wide periphery contact by a steel frame inclined at an installation angle of 65° to the horizontal. (Such an angle was selected for the test because flight of rotary-wing aircraft is in the nose-down attitude.) The panel was attached to the

frame with 1/4 in. bolts fastened to an average torque of 20 in.-lb. All tests were conducted at a room temperature of $70 \pm 5^{\circ}\text{F}$ and the 4-lb bird impacted at the center of each panel. High speed film coverage was included for each shot to enhance the analysis of the performance.

The bird gun at the National Research Council consists of a long 12-in.-diameter barrel attached to an air pressure chamber. Figure 27 shows the bird gun pointed at a panel prior to an actual shot. By separating the barrel at the flange shown along the left of Figure 27, a 4-lb bird package is positioned within an aluminum honeycomb carrier. The bird was freshly killed, frozen, and recently thawed for the test. The bird weight and the total package were previously measured to the nearest gram. After fastening the flanges together, the chamber is pressurized to the required pressure. Actual triggering is accomplished by a quick pressure relief in an intermediate chamber. The bird in the aluminum carrier travels the length of the barrel where a flange at the end of the barrel stops the carrier. The bird package is thus released to impact the sample. The actual velocity at impact is calculated from the time necessary for the bird to traverse a given distance as sensed by two independent photocell systems. The velocity, as measured, was within $\pm 3\%$ of the requested level and all impacts struck the geometric center of the panel.

In addition to the high speed film coverage, photographs were taken before and after each test. A typical test setup with test panel 21 attached to the frame at 65° inclination relative to horizontal is shown in Figure 28. The extra steel extending above and below the horizontal cross members of the frame permits expansion of the frame inside opening to accept larger panel sizes. The frame was rigidly supported by large structural steel I-beams that were permanently anchored.

TEST RESULTS

Figures 29 through 41 show the sample design and results of the bird impact tests. The figures are tabulated in order of design groups, with the front figure of each group showing the basic construction of that group. All photographs in each group show the damage and relative performance achieved after the impact test at the velocity indicated. The photographs are arranged with the outside or impact side at the left and the inside view at the right of each figure. In some cases where an inside view was not available, a close-up of the outside view is shown. In a particular group, the results are presented in increasing order of velocity and not in actual order of the shots. The shot number for each panel tested shown in the outside view designates the actual order of testing.

Stretched Acrylic

Figure 30 shows the results of 4-lb bird impacts of 1/4-in. stretched acrylic design as shown by Figure 29 at velocities of 100 and 150 mph. In

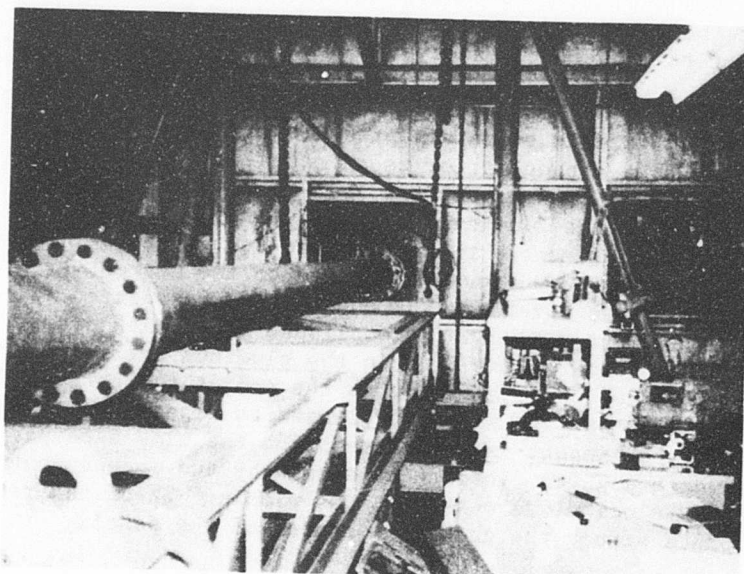


Figure 27. Bird Impact Test Facility Showing
Gun Barrel Pointing at Panel.

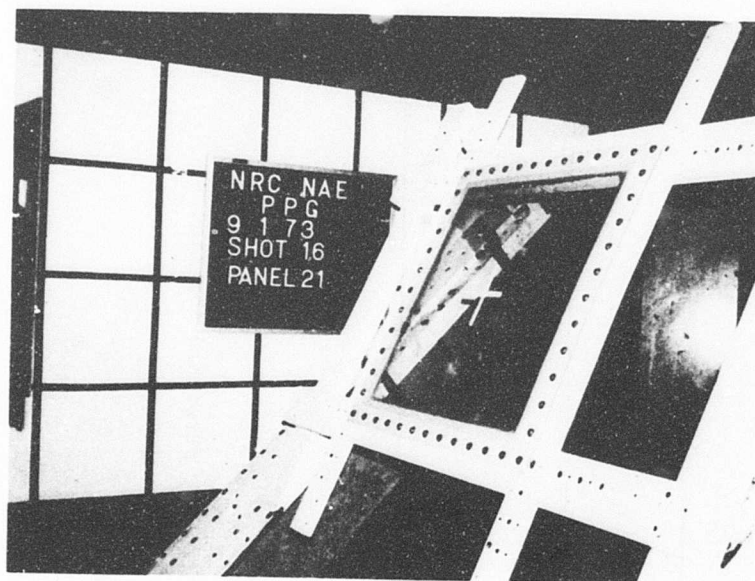


Figure 28. Typical Impact Test Setup of
26-In. X 26-In. Panel at 65°
Installation Angle, $70 \pm 5^{\circ}\text{F}$.

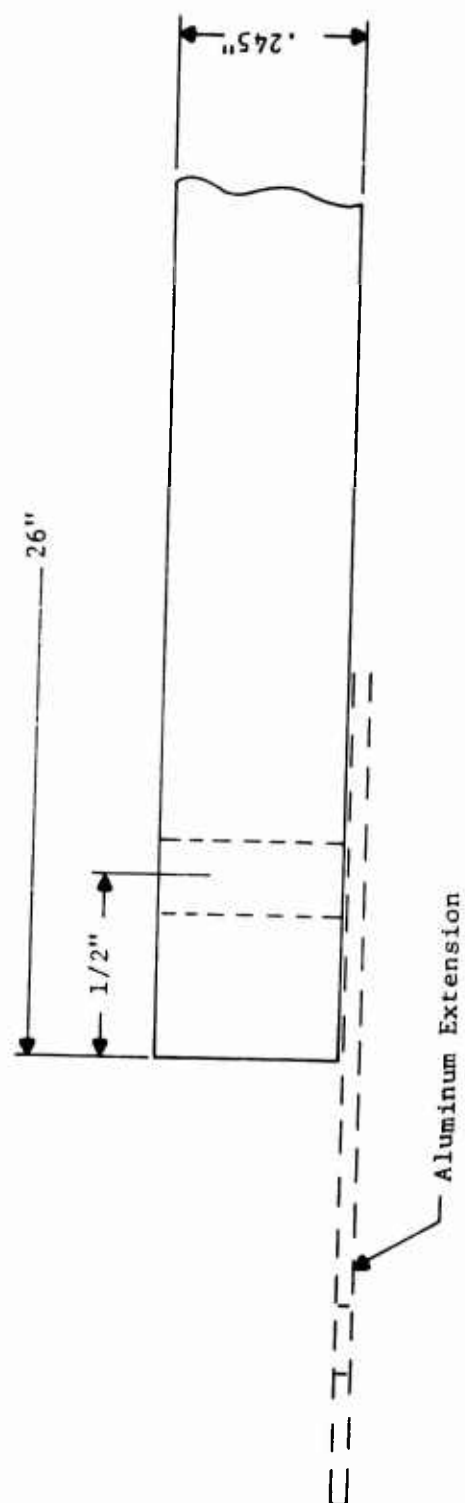
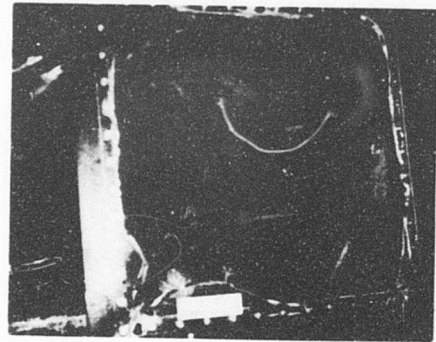
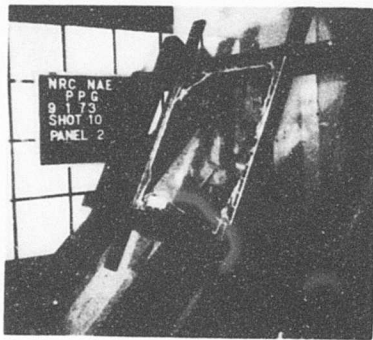


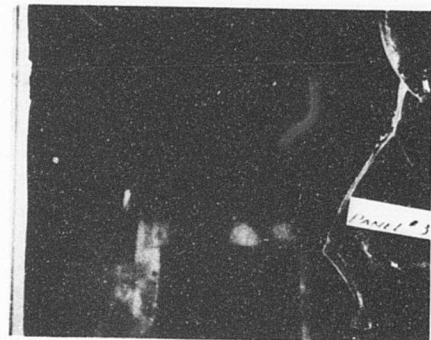
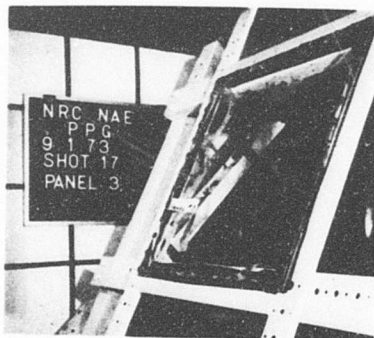
Figure 29. Design I: Monolithic 1/4-In. Stretched Acrylic.



Forward

Panel No. 2 at 101 MPH

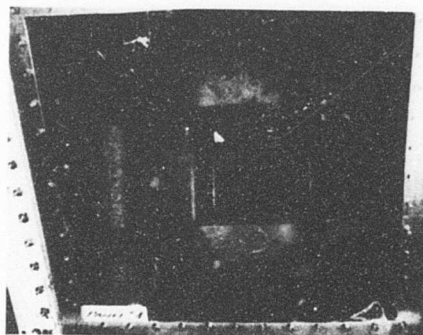
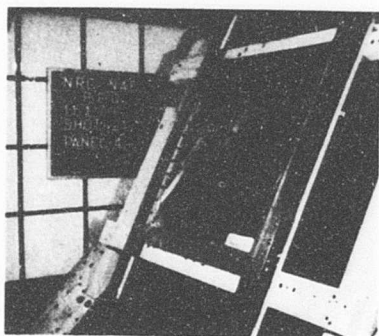
Close Up Forward View



Rear View

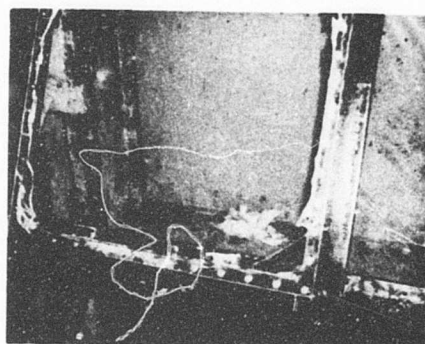
Panel No. 3 With Rubber Gasket at 100 MPH

Figure 30. Results of 4-Pound Bird Impact Tests of 1/4-In. Stretched Acrylic.



Rear View

Panel No. 4 With Flexible Aluminum Extension Ring at 100 MPH
Forward



Close Up Forward View

Panel No. 1 At 151 MPH

Figure 30. Continued.

all cases the bird easily penetrated the acrylic. The entire package went through the opening with nothing being deflected over the frame. This was ascertained by the lack of any bird remains on the upper frame edge or above the frame and from review of film coverage.

After panel No. 1 showed a complete failure with no resistance at 150 mph, panel Nos. 2, 3 and 4 were shot at 100 mph. As shown in Figure 30, panel No. 2 offered no resistance to the 4-lb bird. The fracture was entirely brittle with no material deformation. The apparent origin was located at a drilled bolt hole. Therefore, subsequent tests at the same velocity utilized modifications to enhance the performance. Addition of a .030-in. rubber gasket between the contacting surfaces of the acrylic and frame produced no advantage, as shown by the photographs of panel No. 3.

The final modification to improve the material performance consisted of a flexible aluminum .060-in. extension ring that was bolted to the expanded steel frame. Although the acrylic sample attached to this aluminum ring achieved a more flexible support, the 4-lb bird easily penetrated the sample. Some larger pieces remained attached to the ring, as shown by the photographs of panel No. 4, indicating that the ring did absorb some energy. However, deformation of the ring was minor and the failure continued to start at a bolt hole.

In general, these tests indicated that stretched acrylic is a rather brittle material when subjected to impact especially if some structural damage is present. Undoubtedly, the use of drilled holes through this material without reinforcement seriously weakened stretched acrylic's impact resistance to the bird strikes. Although this inherent problem could be eliminated by attachments, as now used on aircraft as shown in Appendix III, the severe vulnerability of this material to damage would always be suspect.

Polycarbonate

Figures 32 and 33 show the performance of 1/4-in. polycarbonate impacted with a 4-lb bird at velocities of 200 to 275 mph. The design of the samples of this material is shown by Figure 31. Consistent with the other monolithic plastics, holes were drilled through the material and tested without the addition of reinforcement or bushings. Except for a 1-in. periphery border, the polycarbonate samples were covered with an ultra-thin protective layer, OI-650 hard coat. The results shown by Figure 32 are for optically perfected polycarbonate, whereas the results shown by Figure 33 are for the material as received, which does not attain windshield optical quality.

The results per Figure 32 show that 1/4-in. polycarbonate, optically perfected with hard coat, bounced the bird at 200 mph but was penetrated at 250 mph. At 200 mph, a few cracks developed around the bolt holes along the top edge. The major amount of bird remains around the top of the frame for the 250 mph impact of panel No. 6 indicates the panel showed some resistance to penetration. The failure started in the vicinity of the second bolt hole

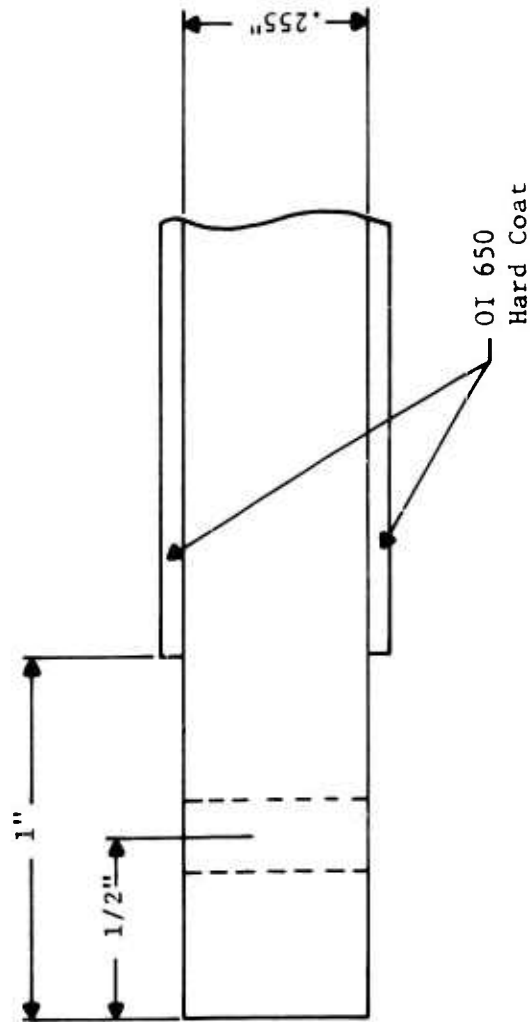
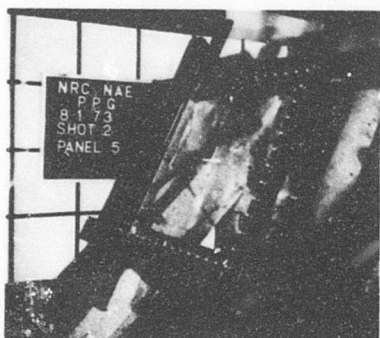
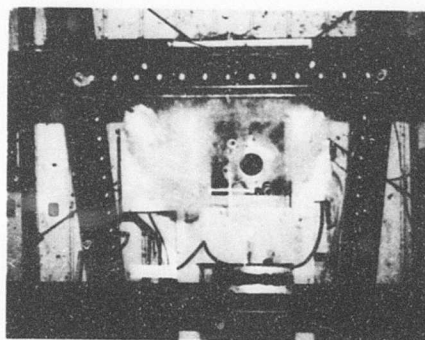


Figure 31. Design II: Monolithic 1/4-In. Polycarbonate with Hard Coat.

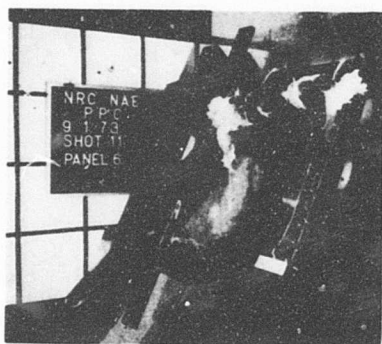


Forward



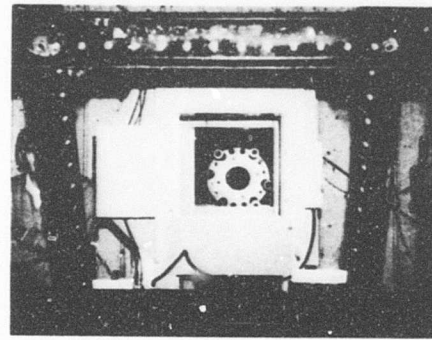
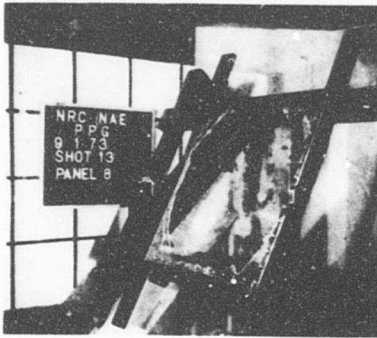
Rear View

Panel No. 5 at 200 MPH



Panel No. 6 at 250 MPH

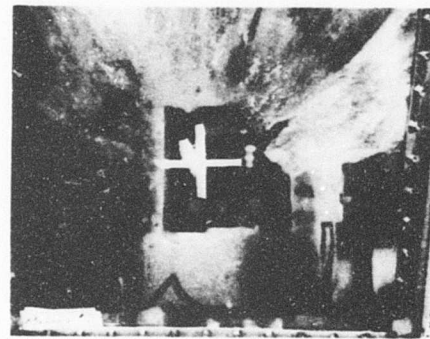
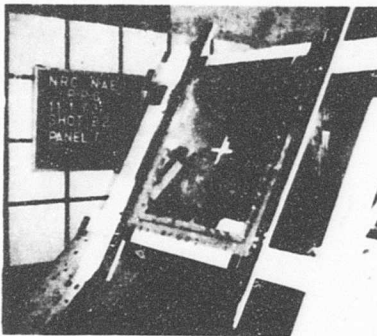
Figure 32. Results of 4-Pound Bird Impact Tests of Optically Perfected, Hard Coated 1/4-In. Polycarbonate.



Panel No. 8 at 250 MPH

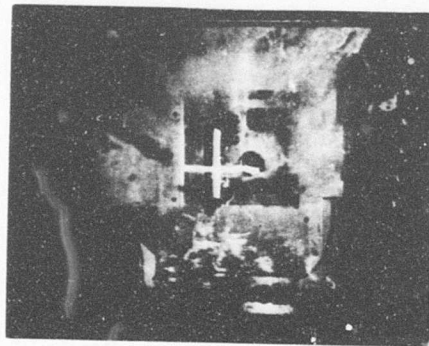
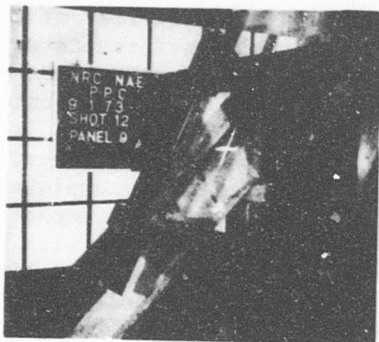
Forward

Rear View



Panel No. 7 With Flexible Aluminum Extension Ring at 250 MPH

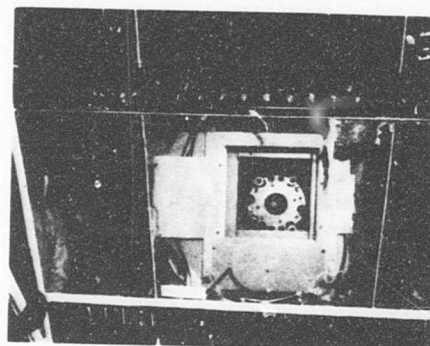
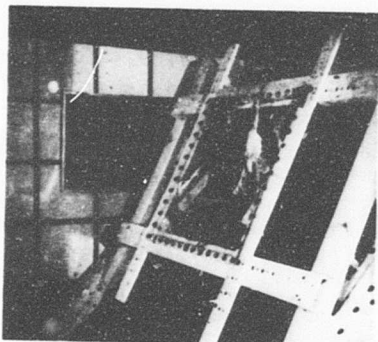
Figure 32. Continued.



Panel No. 9 at 245 MPH

Forward

Rear View



Panel No. 10 at 277 MPH

Figure 33. Results of 4-Pound Bird Impact Tests of As-Received, Hard Coated 1/4-In. Polycarbonate.

upper left corner. Since the actual origin was on the outside surface, the effect of corner rigidity caused this panel to fail. A repeat test at the same velocity of 250 mph also showed penetration, but the performance as shown by the photographs of panel No. 8 does not resemble the previous test. The bird completely destroyed the panel and went through the frame opening.

Incorporation of the flexible extension as discussed previously for acrylic showed a definite advantage for panel No. 7. The polycarbonate completely bounced the bird without any structural damage at 250 mph. Under impact, both the polycarbonate and the extension ring suffered deformation with a final permanent set or bulge of 1.5 in. left in the polycarbonate relative to the initial installed reference. A considerable amount of hole deformation in the aluminum occurred at the bolt holes along each edge, but no complete tear-outs developed. A crack developed in the aluminum at all four inside corners that ran diagonally from the corner to each attachment hole. Other than the permanent bulge and hard coat crazing, no damage that could be considered as a failure inception was detected.

Figure 33 shows the bird strike test results for coated polycarbonate as received without processing to perfect the optical quality. The results tend to show an improved performance for the as-received material, since a 4-lb bird impact at 245 mph was totally defeated by panel No. 9. Consistent with other polycarbonate panel impacts, a corner bolt head was sheared off. This continues to demonstrate the effect of the rigid corner where the polycarbonate is experiencing high tension stresses on the impacted surface. The inside or rear view of panel No. 9 shows extensive crazing around the impact area. Although the hard coat is not a brittle lacquer, the concentric, high density of crazing on both surfaces indicates high radial tension stresses. However, no comparison between actual locations was possible.

A subsequent test at 277 mph produced total failure of panel No. 10 with the origin starting at the second bolt hole upper left corner. In general, these results would indicate that the optical perfection processes can cause a minor reduction in the impact capability. However, the sample size is too small for definite conclusions.

Two-Ply Glass Laminates

Figure 35 shows the results of 4-lb bird impacts of two-ply glass laminates as per the design shown by Figure 34. The insert system with silicone produces a flexible edge design that would not transfer mounting stresses to the structural members. Performance as shown by the photographs along the top of Figure 35 indicates this all glass panel bounced the bird, but a tear developed along the lower right corner of panel 12. Therefore, the results from this test would be "bounced bird but penetration occurred".

A second test at 100 mph of panel No. 11 attached to an aluminum extension ring demonstrated no advantage. In fact, the results were inferior, since

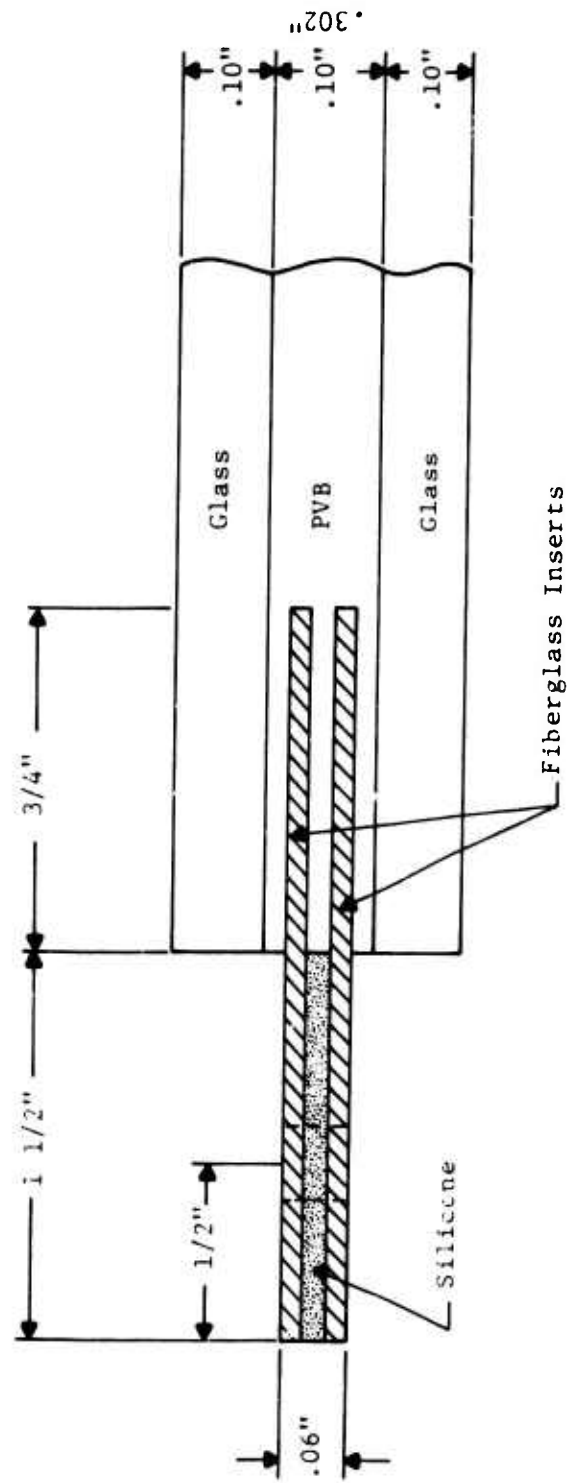
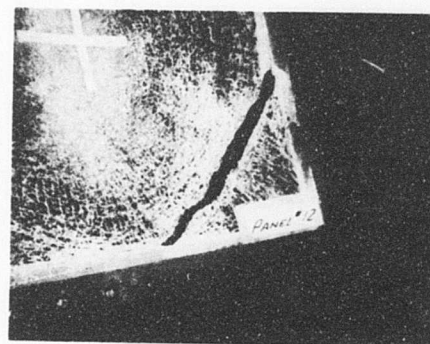
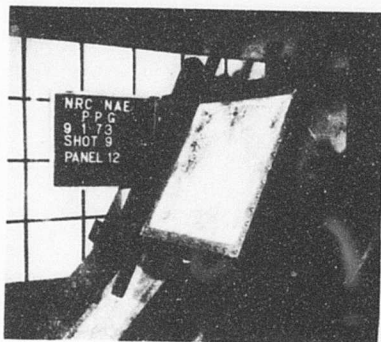


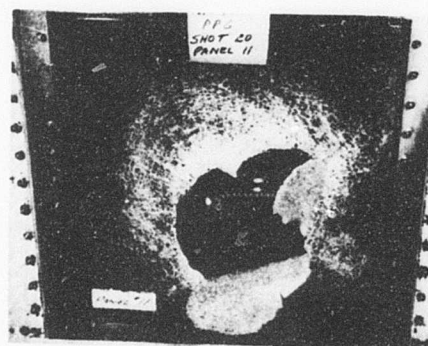
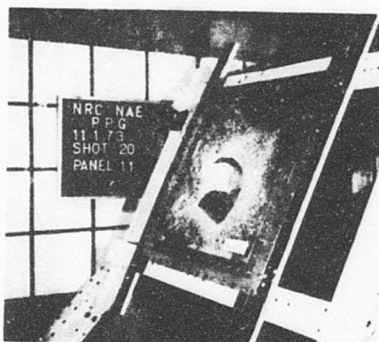
Figure 34. Design III: Two-Ply Glass Laminate
 .10-In. Glass - .10-In. PVB Interlayer -
 .10-In. Glass.



Close Up Forward View

Forward

Panel No. 12 at 102 MPH



Rear View

Panel No. 11 With Flexible Aluminum Extension Ring at 100 MPH

Figure 35. Results of 4-Pound Bird Impact Tests of .10-In. Glass - .10-In. PVB Interlayer - .10-In. Glass.

the bird went right through the panel, leaving a 9-in.-diameter hole. Thus, it would appear that impact of panel No. 11 resulted in minimal amount of load transfer to the edging.

Unbalanced Glass-Polycarbonate Composites

Figure 36 presents the unbalanced design of glass-polycarbonate panels tested with 4-lb bird impacts at 100 to 250 mph as shown by Figure 37. The polycarbonate was optically perfected and the transparent structural members bonded by a special interlayer proprietary to PPG Industries. The exposed polycarbonate surface was hard coated. Both panel Nos. 15 and 13 bounced the bird at 104 and 147 mph, respectively, with excessive crazing of hard coat at the higher velocity. Although panel No. 13 bounced the bird, the energy at impact was such that no residual vision remains as shown at the bottom right of Figure 37. Conversely, some residual vision remained for the lower impact velocity of panel 15. In addition, the top edge attachment of panel No. 13 was forced up by the impacting bird. This demonstrates an inherent problem with outside surface edge attachments subjected to bird strikes.

In subsequent higher velocity impacts, the impacting bird was captured within the panel construction. At 201 mph, panel No. 16 as shown along the top of Figure 37 captured the majority of the bird between the glass and interlayer attached to the polycarbonate. This was repeated by panel No. 14 at 250 mph, but the sharp claws of the bird caused a crack in the polycarbonate. Hence, at 250 mph, penetration was attained with one complete foot of the bird through the crack, as shown by the lower right photograph of Figure 37.

Three-Ply Glass Laminates

Figure 39 presents the results of 4-lb bird impacts of three-ply glass laminates as constructed per Figure 38 at velocities from 100 to 150 mph. The insert system as utilized on this design produced a very rigid edge. Up to 126 mph, this design with an additional glass ply bounced the bird, whereas a catastrophic failure occurred at 151 mph. At 126 mph, all three glass plies of panel No. 19 failed, but the bird was defeated. No residual vision remains for panel No. 19, as shown by the right center photograph of Figure 39. In comparison to the two-ply design, the addition of an extra ply with associated interlayer added about 50 mph to the penetration level.

Balanced Glass-Polycarbonate Composites

Results of 4-lb bird impacts of balanced glass-polycarbonate design per Figure 40 are shown on Figure 41. This design included 1/8-in. polycarbonate as-received buried between a special interlayer proprietary to PPG Industries. As shown by Figure 41, this balanced design, which could be considered as an additional glass ply attached to design IV, sustained

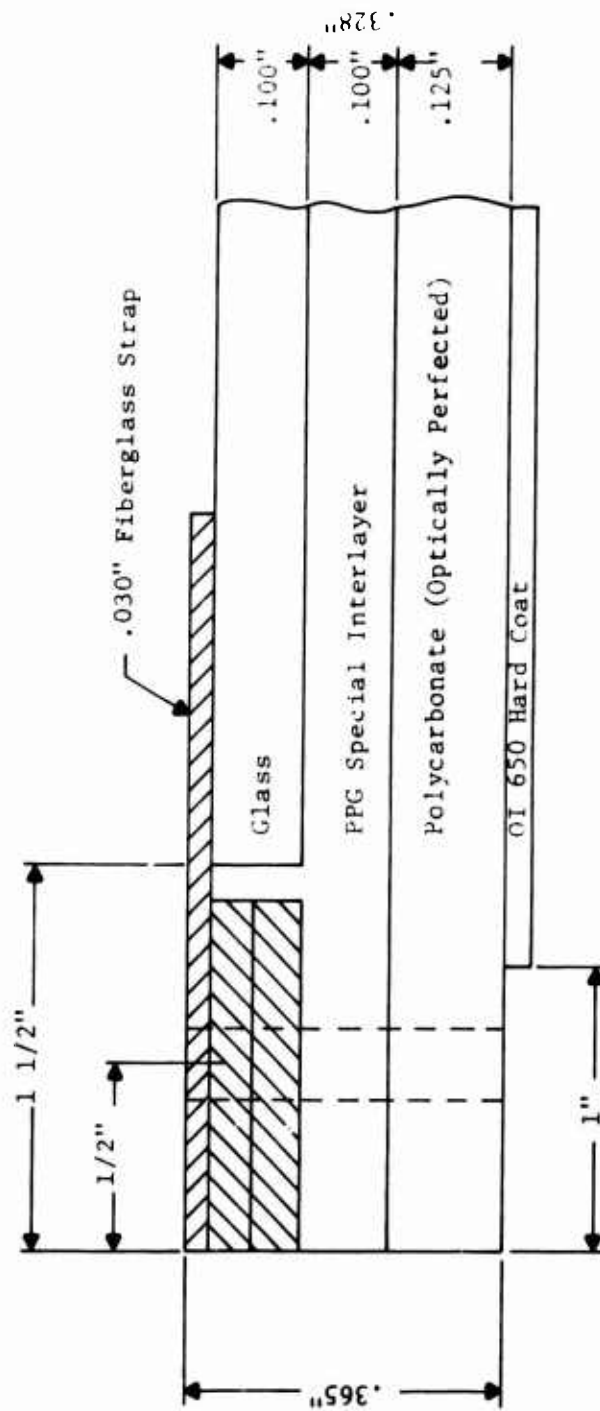
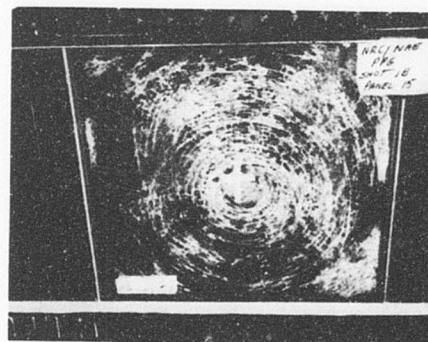
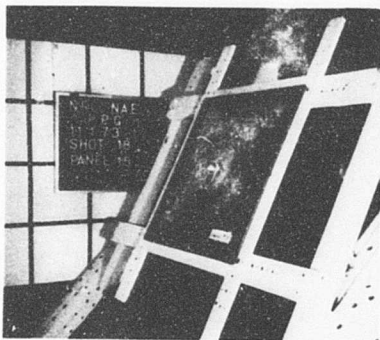


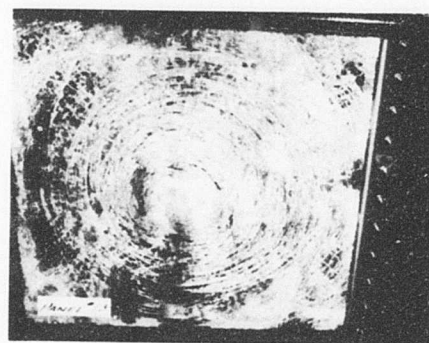
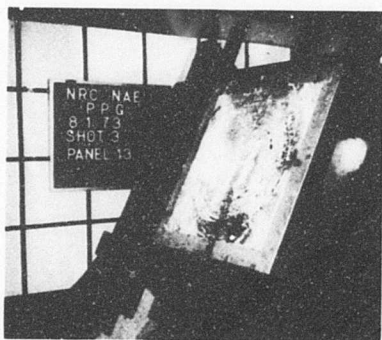
Figure 36. Design IV: Unbalanced Glass-Polycarbonate Composite
 .10-In. Glass - .10-In. Special Interlayer - .125-In.
 Polycarbonate.



Panel No. 15 at 104 MPH

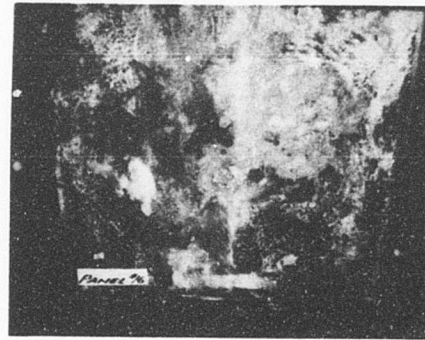
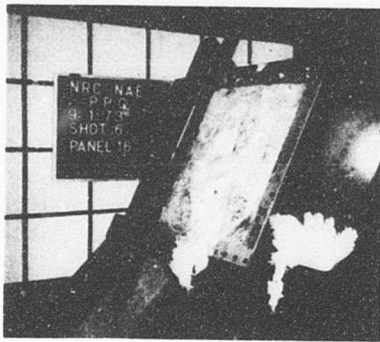
Forward

Rear View



Panel No. 13 at 147 MPH

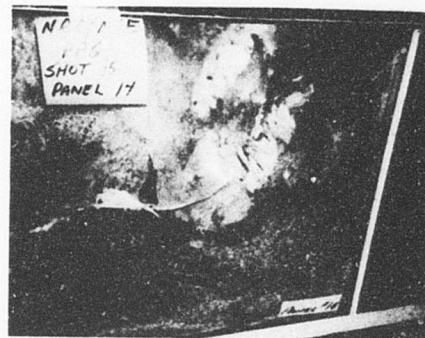
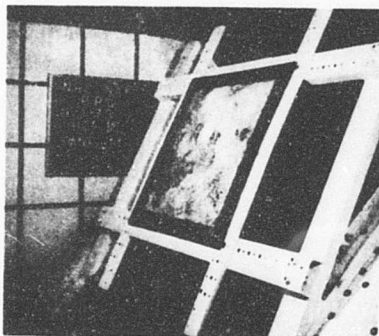
Figure 37. Results of 4-Pound Bird Impact Tests of .10-In. Glass - .10-In. Special Interlayer - .125-In. Polycarbonate With Hard Coating.



Panel No. 16 at 201 MPH

Forward

Rear View



Panel No. 14 at 250 MPH

Figure 37. Continued.

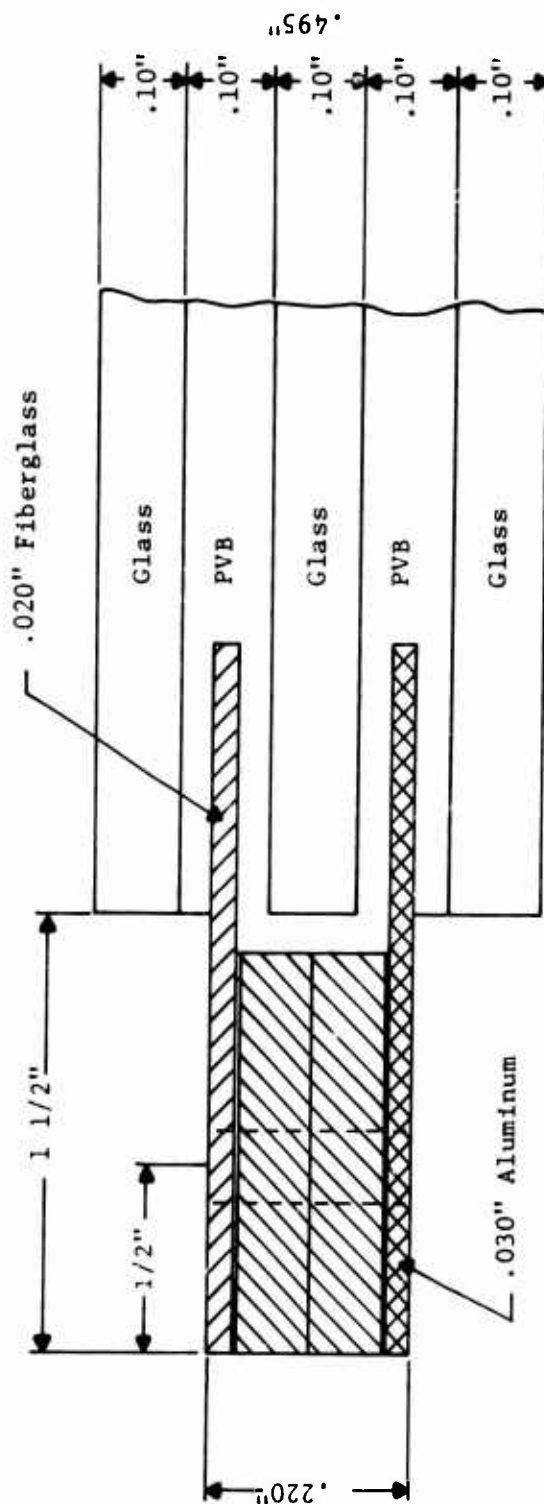
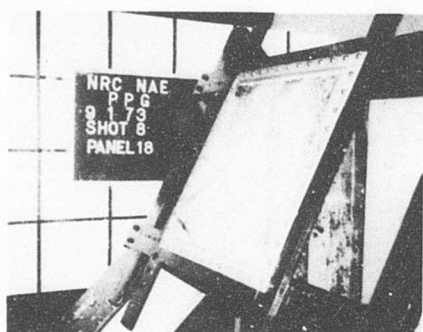
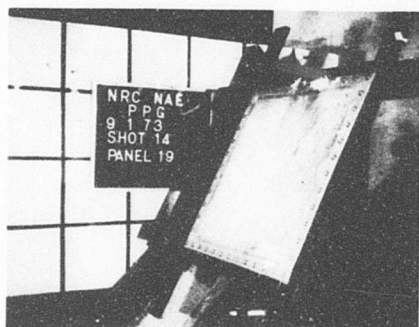


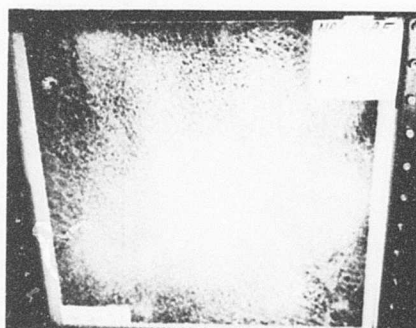
Figure 38. Design V: Three-Ply Glass Laminate
 .10-In. Glass - .10-In. PVB - .10-In.
 Glass - .10-In. PVB - .10-In. Glass.



Panel No. 18 at 102 MPH

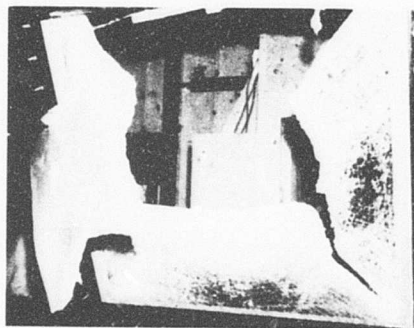
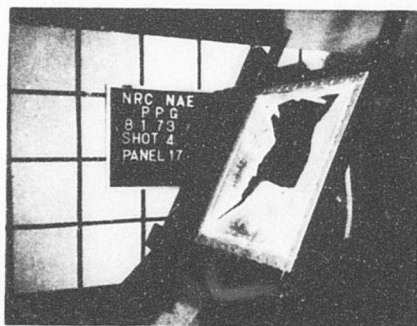


Forward



Rear View

Panel No. 19 at 126 MPH



Panel No. 17 at 151 MPH

Figure 39. Results of 4-Pound Bird Impact
Tests of .10-In. Glass - .10-In. PVB -
.10-In. Glass - .10-In. PVB - .10-In.
Glass Assembly.

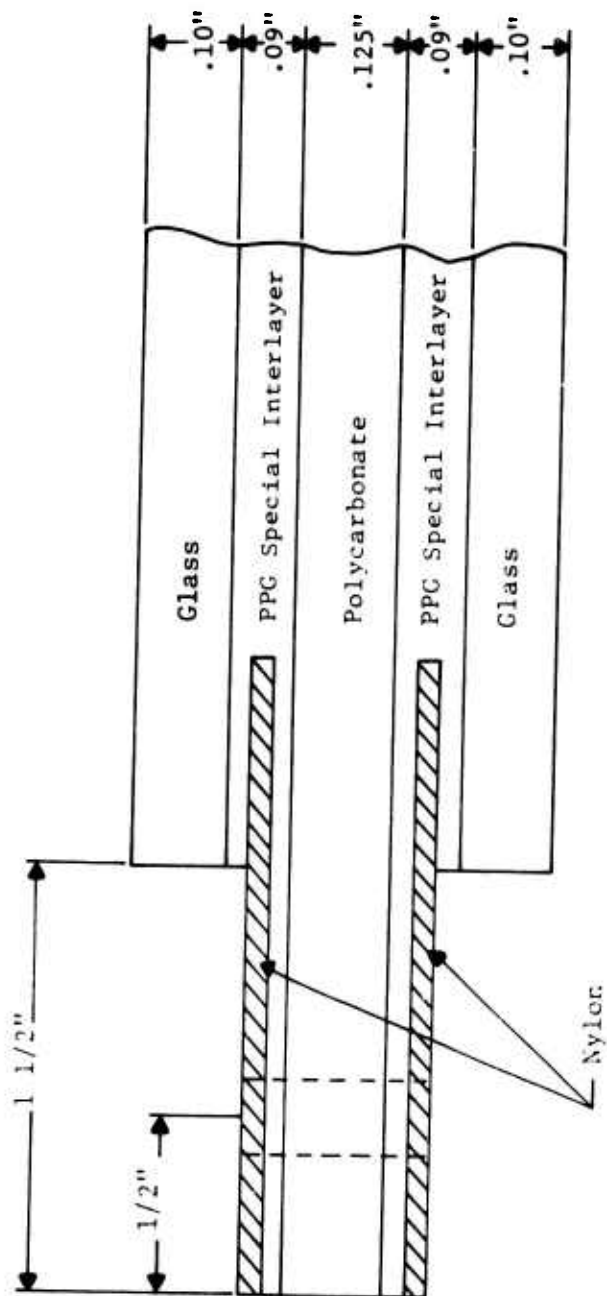
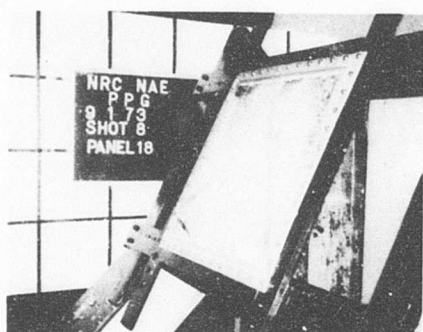
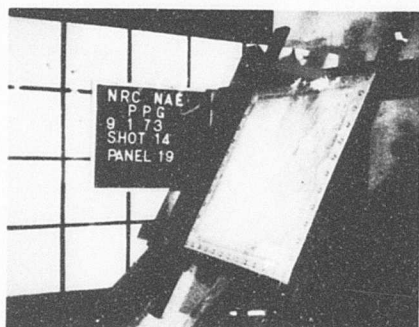


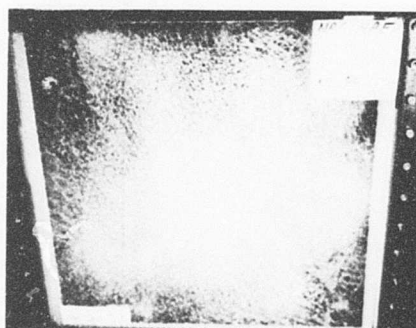
Figure 40. Design VI: Balanced Glass-Polycarbonate Composite
 .10-In. Glass - .09-In. Special Interlayer - .125-In.
 Polycarbonate - .09-In. Special Interlayer - .10-In.
 Glass.



Panel No. 18 at 102 MPH

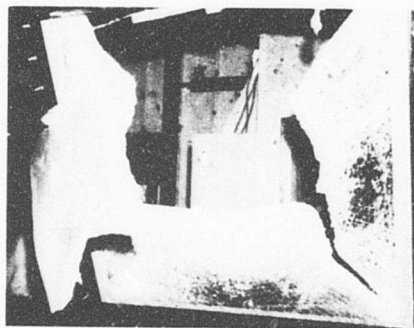
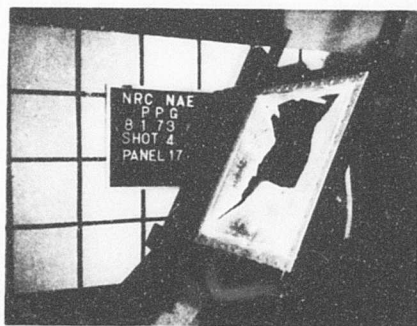


Forward



Rear View

Panel No. 19 at 126 MPH



Panel No. 17 at 151 MPH

Figure 39. Results of 4-Pound Bird Impact
Tests of .10-In. Glass - .10-In. PVB -
.10-In. Glass - .10-In. PVB - .10-In.
Glass Assembly.

4-lb bird impacts at 203 and 253 mph. No residual vision is apparent for either panel No. 20 or 21. Although both panels bounced the bird in all directions, some permanent deformation developed. A final bulge of 1 in. and 2-1/2 in. remained in the panels subjected to 203 and 253 mph, respectively.

DISCUSSION OF RESULTS

Results of the 4-lb bird impact tests tabulated on Table 63 indicate that the two designs now used as windshields do not have a 4-lb bird resistant capability beyond 100 mph. Conversely, designs utilizing polycarbonate, monolithic or laminated, better than double the bird resistant capability of current windshield types. The results as obtained for the unbalanced glass-polycarbonate design cannot be transferred to the presently utilized glass-acrylic windshields because polycarbonate has better than twice the bird resistant capability of acrylic and the interlayers also differ.

Considering all aspects, the balanced glass-polycarbonate design appears to be the most reasonable way to defeat the bird. Although an unbalanced glass-polycarbonate construction is quite comparable to the balanced design for bird resistance, the inherent problems of fabrication and reliability appear more difficult at the present. The primary advantage of the balanced design is the complete interlayer containment of the polycarbonate. Figure 42 illustrates the penetration limits for all designs tested on the basis of aerial density.

TABLE 63. BIRD STRIKE PERFORMANCE OF 26-IN. X 26-IN.
PANELS 4-POUND BIRD, 65° INSTALLATION, 70°F

Part No.	Impact Velocity (mph)	Total Bird Weight (lb)	Density Weight/Area (psf)	Penetration
Design I <u>Stretched Acrylic</u>				
2	101	4.31	1.55	Yes
3	100	4.15	1.55	Yes
4*	100	4.18	1.55	Yes
1	151	4.03	1.55	Yes
Design II <u>Polycarbonate, Optically Perfected, Hard Coated</u>				
5	200	4.19	1.68	No, Bird Bounced
6	250	4.03	1.68	Yes
8	250	4.23	1.62	Yes
7*	250	4.04	1.68	No, Bird Bounced
<u>Polycarbonate, As Received, Hard Coated</u>				
9	245	4.20	1.64	No
10	277	4.16	1.62	Yes
Design III <u>Two-Ply Glass Laminates</u>				
12	102	4.29	2.71	Yes
11*	100	4.20	2.68	Yes, Bird Bounced
Design IV <u>Unbalanced Glass-Polycarbonate Composite</u>				
15	104	4.22	2.92	No
13	147	4.18	2.86	No
16	201	4.00	2.86	No, Bird Catch
14	250	4.27	2.89	Yes, Bird Catch
Design V <u>Three-Ply Glass Laminates</u>				
18	102	4.20	4.40	No
19	126	4.16	4.35	No
17	151	4.13	4.40	Yes
Design VI <u>Balanced Glass-Polycarbonate Composite</u>				
20	203	4.08	4.00	No, Bird Bounced
21	253	4.13	3.95	No, Bird Catch
*Attached to Frame with Aluminum Extension Ring.				

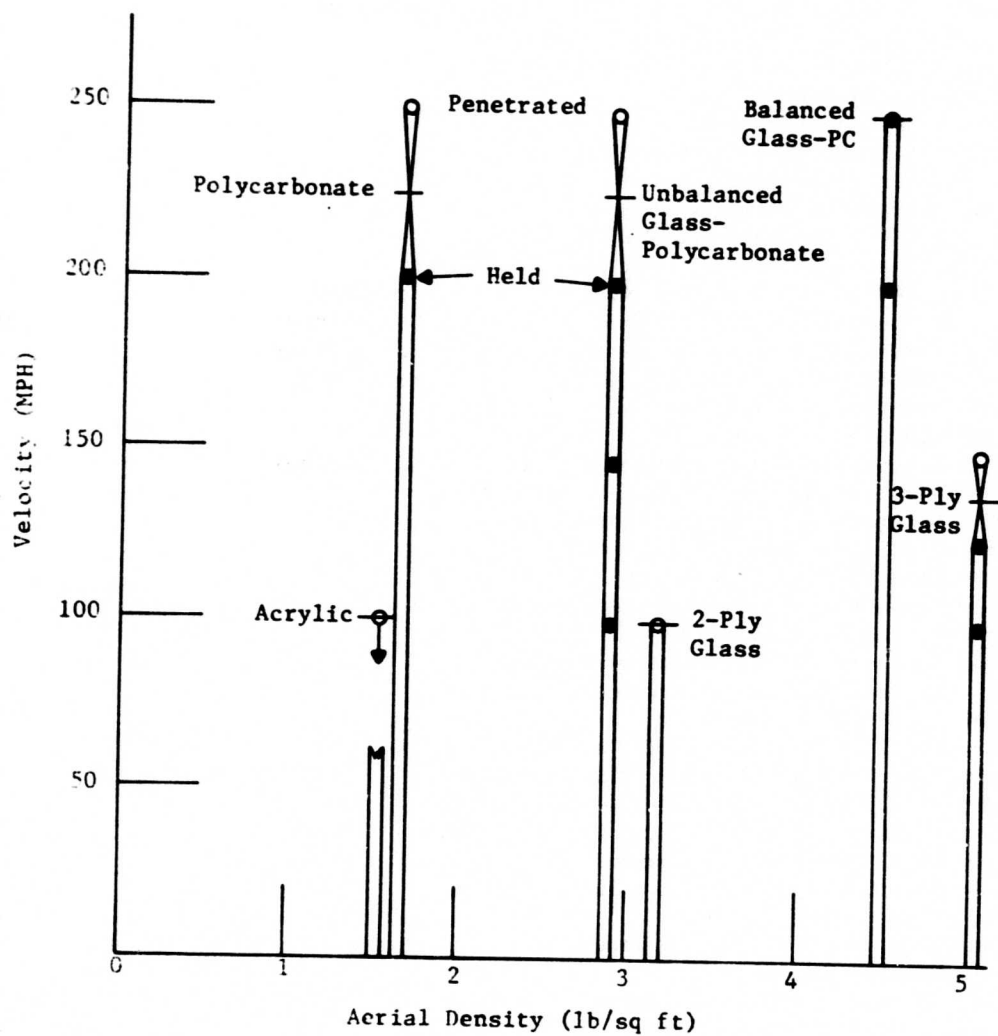


Figure 42. Penetration Limits for Transparent Enclosures Subjected to 4-Pound Bird Impacts at 65° Installation, 70°F.